LOCATE AND RESCUE SYSTEM COMPONENTS

James L. Baker
BAKER DEVELOPMENT CORPORATION
4 Beach Road
Sherwood Forest, Maryland 21405

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PREFACE

During recent years much emphasis has been directed by government agencies and industry toward solving problems of large vessels and aircraft in communications, search and rescue, collision avoidance and navigation. Quite obviously this emphasis is due to the severe economic and environmental impact and catastrophic loss of life that can result from the loss of a large commercial vessel or aircraft.

More recently, some industry and to a larger extent government agencies such as NASA, FAA, U.S. Coast Guard, Drug Enforcement Administration and the AEC, are looking toward the use of satellite systems having greater capability and capacity. These will be designed to accommodate thousands of simultaneous users of low cost equipment for distress alerting, position location and limited communications.

There are many system possibilities for search and rescue or locate and rescue. Today, these systems do not involve satellites, but comprise essentially two types, one using a network radio communications link and the other using a characteristic beacon signal (ELT or EPIRB) on which a rescue aircraft or other mobile vehicle can "home on" in case of accident. Unfortunately, line-of-sight limitations of VHF radio and beacon signals limit the range (approximately 25 miles) between the origin of the distress signal and the mobile rescue unit.

Satellites gain the advantage of almost continuous visibility of the Earth's surface. There is little question as to the superiority of satellites over terrestrial search and rescue systems; however, the better capability of user equipment could cost more than present terrestrial systems.

Numerous concepts have evolved using satellites, and these consist of either one or more low altitude polar orbiting satellites, one or more medium altitude satellites, and one or more synchronous satellites. Any one of several types of modulation systems could be successfully used for satellite communication and position location. Two or three synchronous satellites have the advantage over an equivalent number of low altitude satellites because of continuous visibility of most of the Earth's surface. Their capability permits nearly instantaneous reception of the first distress signal. On the other hand, hours may pass before a low altitude satellite passes in range of the location of a distressed person. The low orbit satellite system generally has the advantage of lower costs for both satellite system and user equipment by substantial amounts.

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INTRODUCTION

This contractual effort embraces component development that is common to either a low Earth orbit or synchronous orbit satellite system for locating and rescuing distressed persons. Although the total cost of this work is less than $10,000.00, it may have ushered in a new era of space applications, involving very low cost user equipment with early availability, to a very large segment of the population. Most important to the successful implementation of this effort, for which I acknowledge my deepest appreciation to Dr. Robert Rochelle, Professor, Electrical Engineering Department, Univ. of Tenn. and his staff for their technical implementation of the Distress Alarm Encoder and to Mr. Julian W. Dees, Director, Electromagnetics Laboratory and his staff for their technical implementation of the Quadrifilar Helix VHF antenna.

BACKGROUND

This development effort was done in support of and as part of NASA's overall program in search and rescue involving satellites. A technical proposal termed "Locate and Rescue Experiment and Demonstration" was submitted by Baker Development Corporation (BDC) on July 22, 1975, to NASA/GSFC for the development of two long-lead components; namely, a distress alarm encoder and a circularly polarized VHF antenna to permit position location and low cost communication between a boat in distress and the existing satellites, ATS-1 and ATS-3.

The technical objectives were to be achieved by extensive testing with the boat equipment and the General Electric Company's ground facilities at Schenectady, N.Y.

The proposal was one of cost sharing in which the yacht COLUMBINE, its onboard equipment, crew and subsistence, would be provided for tests and demonstration without charge to the government. Unfortunately, the lack of funds precluded implementation of the complete development, experimentation and demonstration. Instead, only the development of the long-lead items of the proposal were funded, and the distress alarm encoder interface requirements were modified and enlarged to accommodate operation with the Nimbus-6, ATS-1, and ATS-3 satellites. In order to operate with Nimbus 6, the alarm encoder was designed to interface with the Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE) equipment developed for NASA/GSFC by Texas Instruments.

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TWERLE equipment is operating successfully with NIMBUS-6 and is a most recent experiment and yet another way of obtaining position of, and data from, a weather balloon. In this case the polar orbiting Nimbus 6 satellite is being used to receive and record the varying Doppler shift in the frequencies being transmitted to the satellite. From these Doppler data retransmitted from Nimbus 6 to the ground station, the exact position of each of nearly 400 constant altitude balloons can be determined.

The use of the TWERLE equipment is an expedient in the early phases of the program for search and rescue, because it provides a reliable formatting interface and transmitter between the encoder and the low Earth orbiting satellite, Nimbus 6. In addition to recording a large number of digital coded messages ($\simeq 10,000$), the TWERLE system can determine the origin (position) of the distress message.

It is important to bear in mind that the total cost of a distress system for small seacraft and aircraft must be kept to a minimum. Therefore, it is unlikely that the TWERLE equipment would be used "as is" in an operational sense because of excess capacity, flexibility and high unit cost. Rather, it would be a system designed to provide one to ten precoded messages instead of its present capability of 10,000.

The frequencies to be used with Nimbus 6 from the boat or aircraft are 401.6 MHz; and with ATS-1 and ATS-3, 149.22 MHz uplink, and 135.6 MHz downlink.

After award of the contract, an urgent requirement arose to use the distress alarm encoder aboard a Model T-Ford for transmitting messages and position data during the planned around the world race for antique cars scheduled for early summer 1976.

Unfortunately the car race did not take place as planned and the encoder's use for that purpose is uncertain at the time of this writing. Other immediate uses of the encoder are being planned for special land mobile and aircraft, however.

It should be borne in mind that the contract specifies development and delivery of a distress alarm encoder and a VHF antenna only, and does not authorize experiments, tests and demonstrations aboard a boat, aircraft or any other mobile. It was assumed that additional contract authorization would be provided for such tests and demonstrations at a later date, if desired by NASA.

CONCLUSIONS AND RECOMMENDATIONS

(a) Distress Alarm Encoder

The encoder was interfaced with the RAMS-TWERLE equipment loaned to the Baker Development Corporation by NASA for that purpose. Interfacing and test took place at the University of Tennessee where the equipment was developed. The encoder is smaller in size and weight than required by the specification, and its capacity and flexibility are more extensive than required.

The unit operates as it was designed and is easily interfaced with the TWERLE formatter and transmitter. The encoder is described in detail in Appendix A.

(b) VHF Antenna

The quadrifilar circularly polarized VHF antenna was tested successfully at Georgia Tech. Engineering Experiment Station and meets the requirements of the specification. The antenna development and its characteristics are described in detail in Appendix B.

(c) Recommendations

System installation and test should be initiated as originally proposed aboard the yacht COLUMBINE followed by demonstrations to interested parties as to the reliability, accuracy and low cost capabilities of these satellite systems using these key components developed for this purpose.

APPENDIX A
DISTRESS ALARM ENCODER

University of Tennessee
Electrical Engineering Laboratory
Knoxville, Tennessee

BACKGROUND

The distress alarm encoder, to be used through satellites, is a new concept among emergency signalling devices which is intended to receive signals from individuals lost or in distress while on foot or aboard mobile craft such as airplanes, boats, trucks, or buses. Its uniqueness lies in the ability to know where the signal is emanating, the general type of emergency, its low cost, and simplicity of operation.

1. SPECIFICATION

Weight—The encoder shall have minimum weight not to exceed 5 lb, excluding battery weight.

Size—Encoder dimensions shall not exceed 10 in. in any measurement, and not have a volume greater than 200 cu. in.

Materials & Sealing—

    a.   Case—The case shall be fabricated or molded with either fire resistant plasitc or corrosive resistant metal. The case shall be impervious to moisture and all connectors and glass covers shall be sealed and waterproofed.

    b.   Components—Solid state devices shall be used throughout where possible.

Interface—The encoder output shall be digital and operate into either a power amplifier for direct transmission or into the RAMS/TWERLE data platform for formatting and signal conditioning prior to inputting to a transmitter amplifier.

Encoder Panel—

    a.   The encoder panel shall have a minimum of five buttons, at least four of which shall have temporary labels denoting the type of emergency such as:

        ●   fire on board

        ●   medical emergency

        ●   grounded, sinking

        ●   lost power

        ●   lost

    b.   A breakable glass cover shall be mounted over the top of the power switch or the panel buttons, with a metal plunger (chain mounted) used for breaking glass similar to fire alarm systems. The glass cover shall be gasketed in a manner that will permit its removal without breaking while in flight or underway at sea.

    c.   In operation, the depressing of any button in an emergency will turn on power and transmit a simple coded signal to its output terminals.

Tests—The encoder will contain a simple continuity check with a suitable "Go-No-Go" indication.

Demonstration—The encoder operation will be demonstrated in the GSFC, Code 950, laboratory prior to final acceptance.

2. FUNCTION

    The distress alarm keyer (Figure 1) is designed to interface a touch-tone format keyboard to a conventional data collection platform (DCP). The current hardwired logic design (Figure 2) allows one to four digits, entered from the keyboard, to be presented to the DCP in a parallel, binary coded decimal format. Each digit of the one-to-four digit coded message uses four of the (typically) 32 parallel input bits provided by the DCP. One hundred distinct messages can be transmitted by connecting two of the digit outputs to one 8-bit parallel sensor input of the DCP. The number of distinct messages can be increased to 10,000 by connecting all four of the digit outputs to two of the DCP parallel sensor inputs. When the DCP is not required to transmit data from any other device,

the four-message digits can also be connected to the remaining two parallel sensor inputs so that the message will be sent twice during each transmission. This technique improves the performance of the system under the influence of short noise bursts.

The user must know whether the distress alarm keyer has been wired to transmit one, two, three, or four digits. In any case, the last N digits entered from the keyboard will be transmitted. Here, N is the number of digit outputs wired to the DCP sensor inputs.

3. THEORY OF OPERATION

A block diagram of the distress alarm keyer is illustrated in Figure 3. The device consists of a keyboard encoder and a serial-to-parallel converter housed in two separate boxes. The keyboard unit is designed so that it can be placed in a convenient location at some distance from the serial-to-parallel converter and the DCP. Digits entered from the waterproof, military-quality keyboard are converted to binary coded decimal format and transmitted serially to the serial-to-parallel converter. A valid key entry is acknowledged by a momentarily "on" light-emitting diode. The keyboard encoder also contains a waterproof toggle switch that controls power to the distress alarm keyer and the DCP.

The serial-to-parallel converter accepts the clock and serial data outputs of the keyboard encoder and presents the last 4 keyboard entries to the DCP on 16 parallel lines. Normally, the serial-to-parallel converter will be mounted as close as possible to the DCP to minimize the length of these lines. The specific operation of each circuit is described below.

4. KEYBOARD ENCODER

Figure 4 is a schematic and Figure 5 is a photograph of the keyboard encoder printed circuit. A timing diagram is provided in Figure 6. A1 is a keypad-to-binary encoder that debounces the inputs from the Chomerics military touch-tone keyboard (No. 22229) and provides a strobe signal when a legal key entry (digits 0-9) is detected. The strobe signal parallel loads the data into shift register A2 and resets binary counter A of A5. Binary counter B of A5 then counts the master clock up until a count of 16 is reached and the clock input is disabled. The Q_{ob} Q_{1b} outputs of the B counter form the gated 2X and data (1X) clocks, respectively. The eight-bit shift register (A2) is clocked by the 2X clock and provides serial data to one gate of A3. The data (1X) clock triggers a one shot that drives the light emitting diode (LED_1) through four parallel gates of A3. The remaining gates of A3 convert the 5.6-volt serial data and data (1X) clock levels to the 12 to 14 volt power supply used by the serial-to-parallel converter and the DCP. A separate 5.6-volt lithium battery power
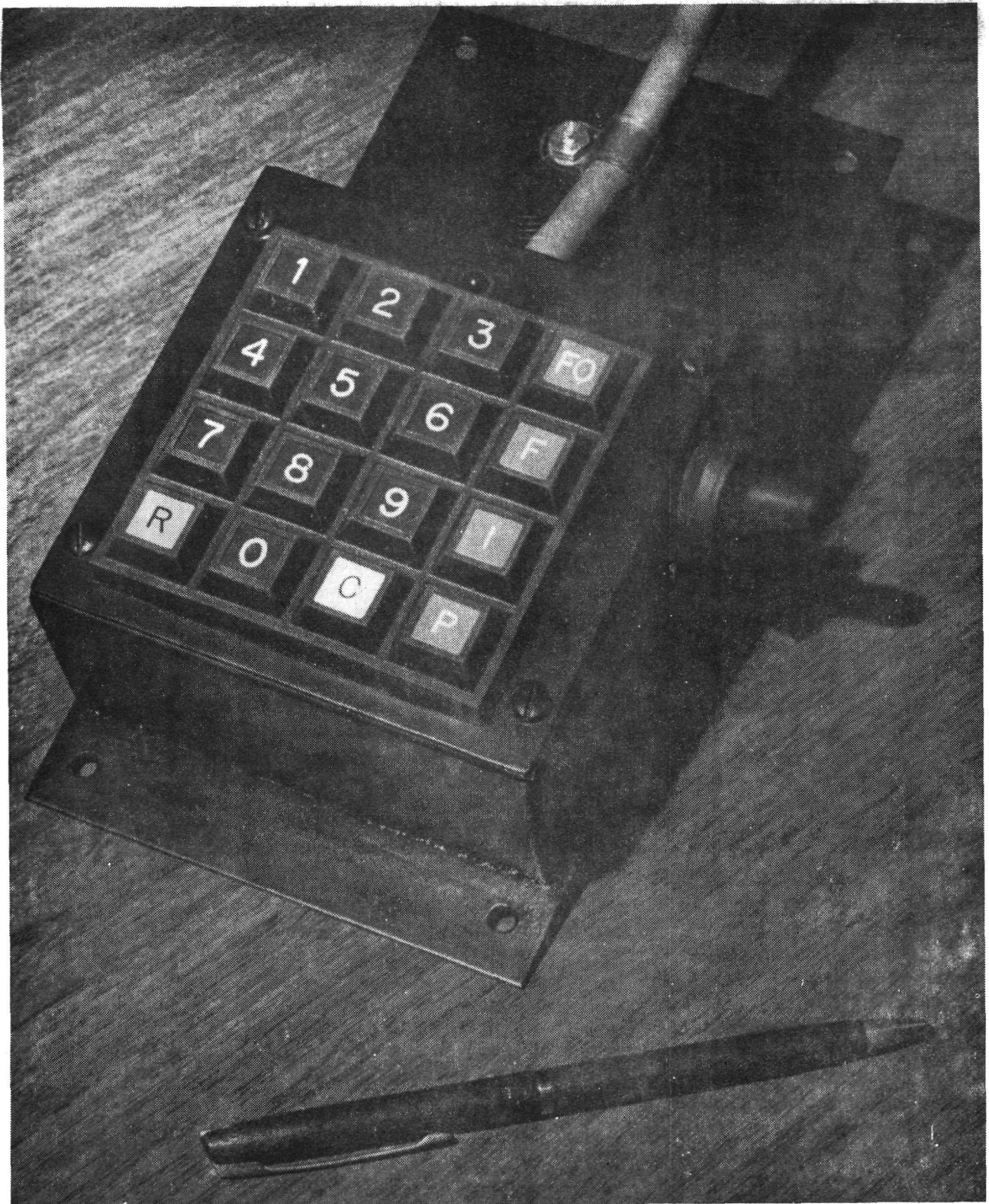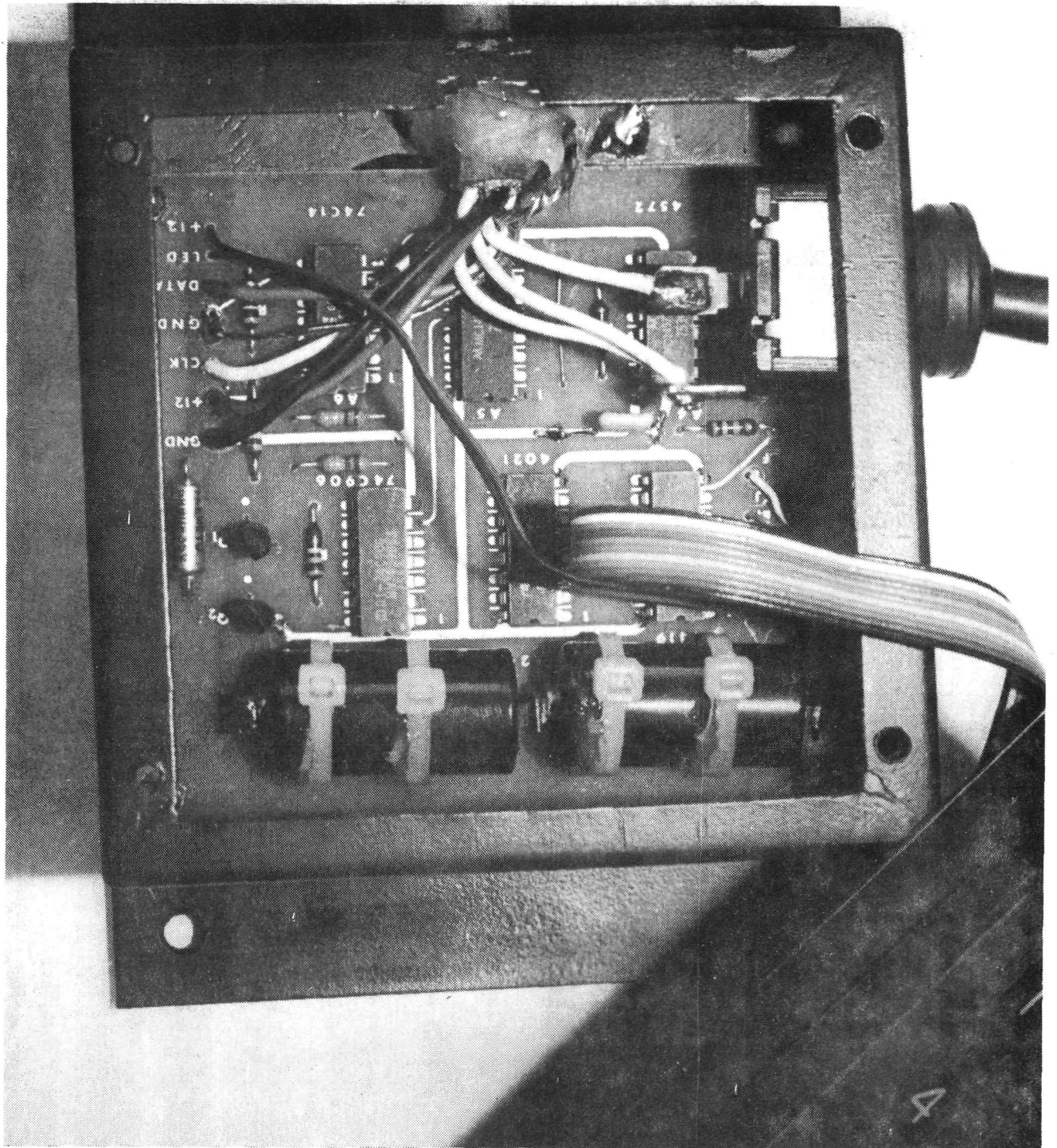
Figure 1. Distress Alarm Keyer
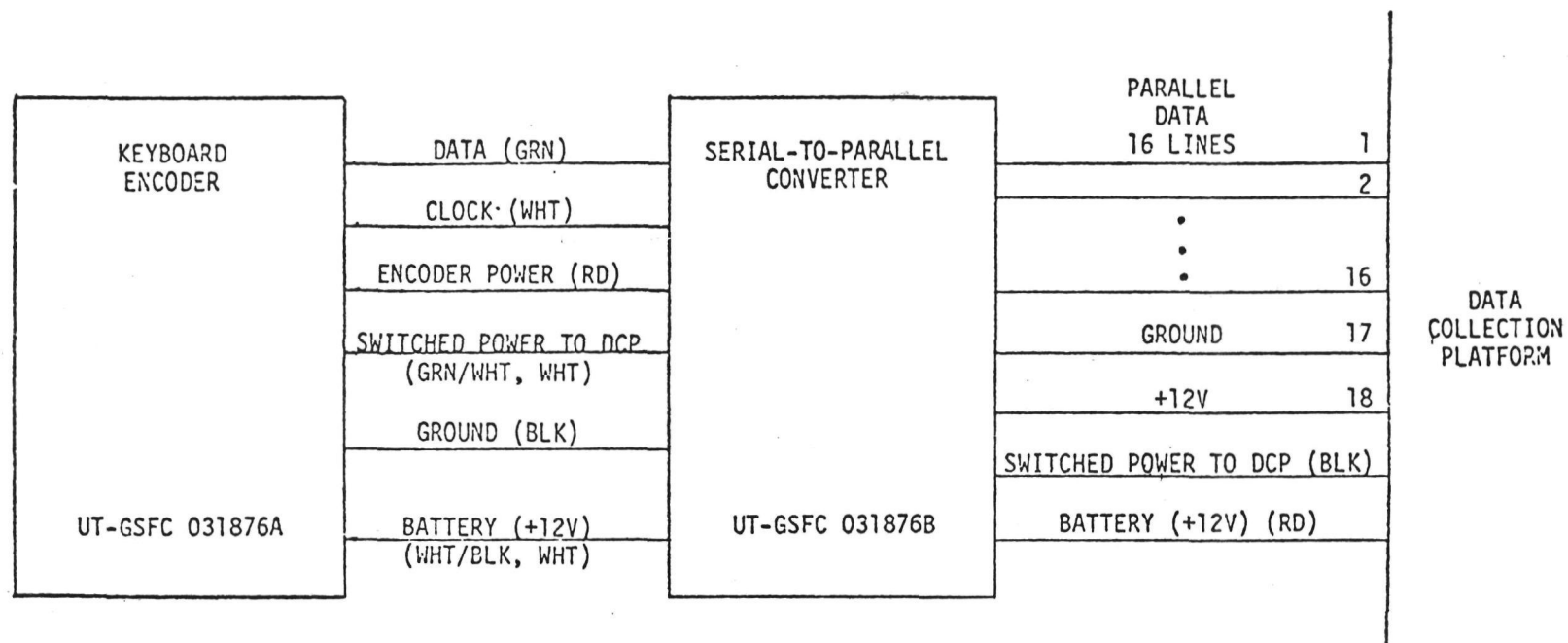
Figure 2. Current Hardwired Logic Design

Figure 3. Distress Alarm Keyer Block Diagram

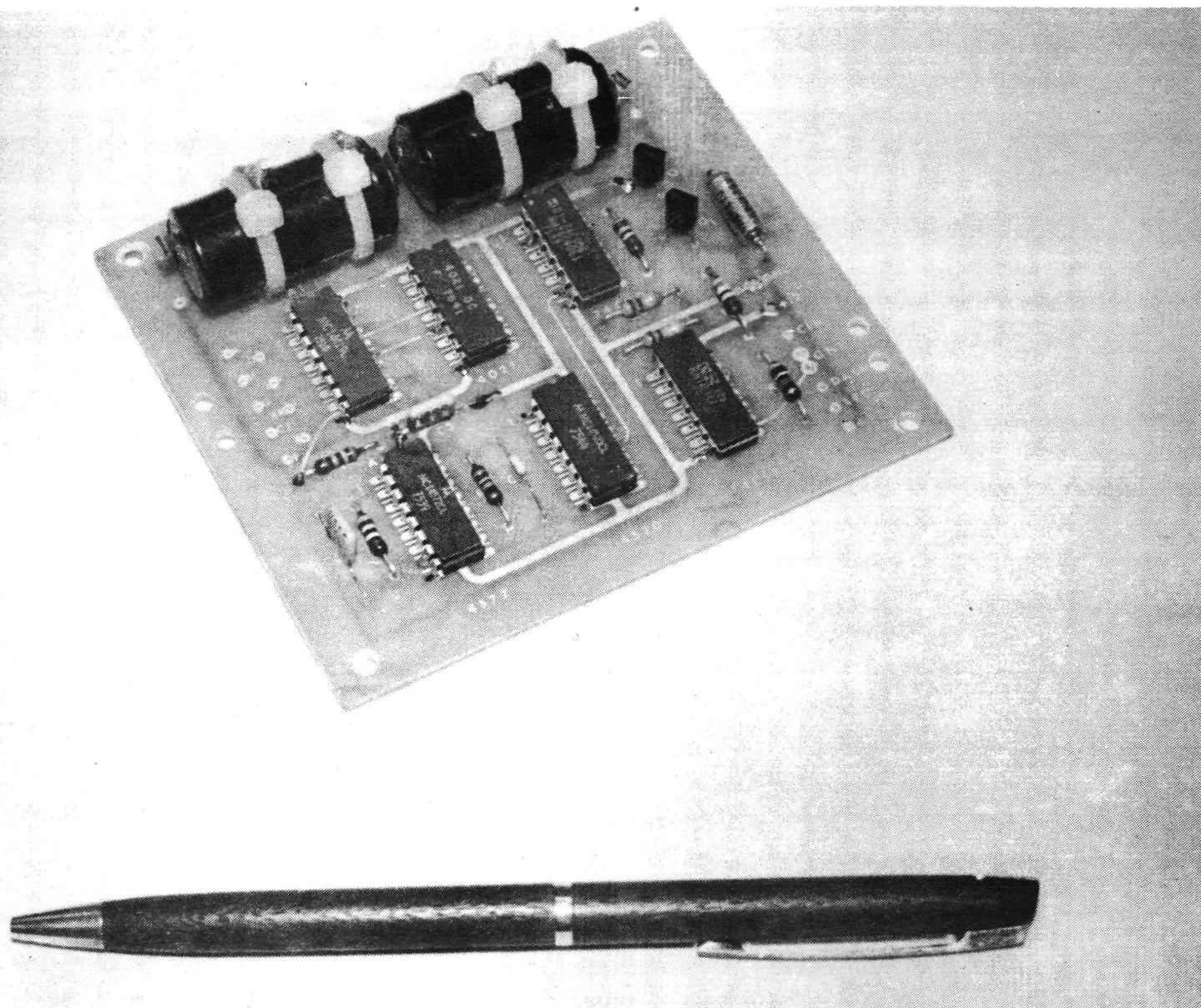Figure 4. Model T Distress Alarm Keyer, Keyboard Encoder

Figure 5. Photograph of Keyboard Encoder Printed Circuit

MASTER CLOCK (4X)

GATED 2X CLOCK
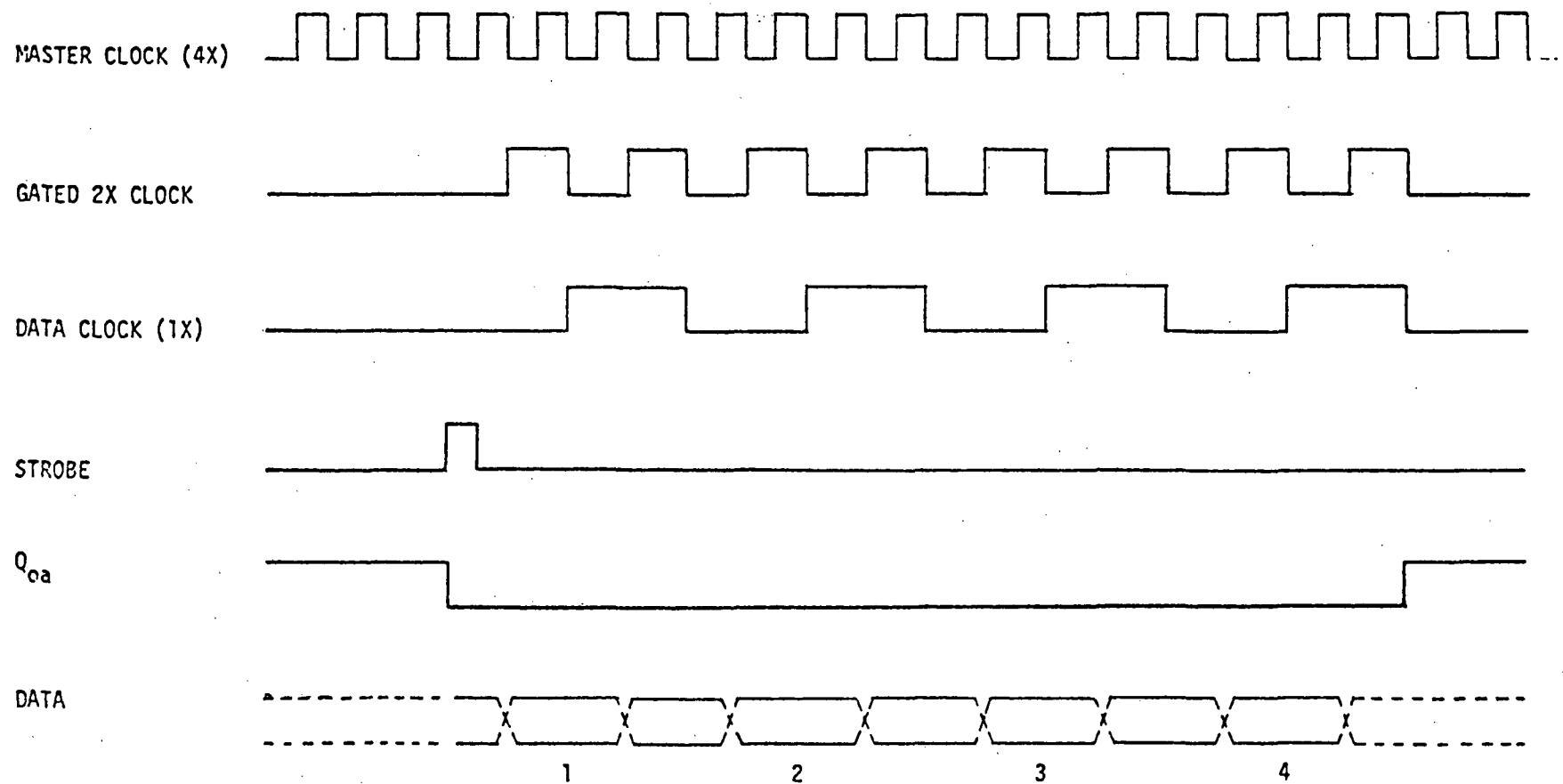
DATA CLOCK (1X)

STROBE

Q_{oa}

DATA

1   2   3   4

Figure 6. Distress Alarm Keyer Timing Diagram

supply with a 1 amphere-hour capacity was chosen for the keyboard encoder circuit to minimize power consumption in the master oscillator circuit and to permit use of the MC14419 keypad-to-binary encoder circuit (A1) which has a maximum supply voltage rating of 6 volts.

The measured current drain from the 5.6-volt battery supply is $<200 \mu$ a that yields a nominal lifetime of 6 months continuous operation or over 1 year of operating 12 hours per day. Quiescent power dissipation from the 12 to 14 volt (nominal) DCP supply is approximately 82μ a. A peak current of 32 ma is drawn from the DCP supply for 50 ms during each key depression. These power consumption figures include power required by the serial-to-parallel converter.

5. SERIAL-TO-PARALLEL CONVERTER

A schematic diagram for the serial-to-parallel converter is illustrated in Figure 7. The serial data and clock inputs from the keyboard encoder are buffered by schmitt trigger inverters (A1) to improve noise immunity. A2 and A3 form a 16-bit shift register with parallel outputs to the DCP. Digit four is the most recently entered data.

74C14
A1

DATA 13 >o 12

CLOCK 1 >o 2

3 >o
5 >o
9 >o
11 >o

UNUSED

4015
A2

7 D_A
6 MRA
9 CP
   D
1 CP
14 MRB

5 A — 1
4 B — 2
3 C — 3
10 D — 4
15
13 E — 5
12 F — 6
11 G — 7
2 H — 8

PARALLEL

DATA

TO

DATA

COLLECTION

PLATFORM

4015
A3

7
6 MRA D_A
9 CP
   D_B
1 CP
14 MRB

5 J — 9
4 K — 10
3 L — 11
10 M — 12
15
13 N — 13
12 P — 14
11 Q — 15
2 R — 16
   — 17
+12 — 18

DIGIT	MSB		LSB	
1	N	P	Q	R
2	J	K	L	M
3	E	F	G	H
4	A	B	C	D

MODEL T DISTRESS ALARM KEYER SERIAL-TO-PARALLEL CONVERTER UT-GSFC 031876B		
IC#	GND PIN	VDD +12
A1	7	14
A2	8	16
A3	8	16

Figure 7. Model T Distress Alarm Keyer, Serial-to-Parallel Converter

APPENDIX B

FINAL TECHNICAL REPORT

VHF ANTENNA FOR

LOCATE AND RESCUE

M. J. SINCLAIR, D. O. GALLENTINE, J. M. SCHUCHARDT

May, 1976

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INTRODUCTION

The broad beamed circularly polarized antenna described in this report will be used in an experiment designed to test concepts involving the use of satellites in locate and rescue emergencies for small craft at sea. In the experiment a small craft at sea will transmit a coded signal representing any one of several emergency situations. The signal will be received by a NASA satellite and relayed to an earth terminal. Within seconds an acknowledgement will be transmitted through the satellite to the craft.

In this situation the antenna should have several characteristics: broad beamwidth capable of horizon-to-horizon coverage, circular polarization to permit arbitrary orientation to a linearly polarized satellite, small and light weight for mounting near the highest point on the craft and rugged to survive the sea and ship environment.

Table 1 summarizes the design goals for the antenna developed on this program.

Table 1

VHF Antenna for Locate and Rescue Design Goals

Parameter	Value
RF Power	Operate up to an input of 300 watts
VSWR Bandwidth	135 to 150 MHz with VSWR no greater than 2 to 1
Polarization	Right hand circular
Axial Ratio	Not greater than 3 dB over the angle $\pm$ 60° from zenith
Pattern	Omnidirectional in azimuth Cardiod in elevation
Gain	0 dB at beam peak. A minimum horizon gain of no less than -6 dB from zenith gain
Size	16 inches maximum diameter 36 inches maximum height

1

Table 1 (Continued)

VHF Antenna for Locate and Rescue Design Goals

Parameter	Value
Mounting	Capable of mast mounting
Operation	Adverse weather, rain, snow and wind gusts to 80 mph
Materials	Non-corrosive materials and/or protection from the effects of salt spray
Temperature	15°F to 125°F

SUMMARY AND CONCLUSIONS

To accomplish the desired antenna design, this project was carried out in three phases:

Phase 1. Given the electrical and physical antenna requirements, choose an antenna type most closely fitting those requirements.

Phase 2. Perform an investigation on the chosen antenna type in an attempt to more closely fit the requirements using available references and designing experiments on prototype antennas.

Phase 3. Construct and test a mechanically sound and electrically compatible antenna.

Broad beamed circularly polarized antennas include the resonant quadrifilar helix, the conical spiral, the planar spiral and the bent turnstile antennas. Difficulties and uncertainties in meeting the design goals existed with each of these antennas; Table 2 lists them.

Table 2

Broad Beamed Circularly Polarized Antenna Comparison [1]

Antenna	Pro	Con
Quadrifilar Helix (QFH)	Good Pattern coverage with excellent circular polarization.	Bandwidth tends to be narrow
Log conical Spiral and Planar Spiral	Adequate zenith gain and bandwidth	Poor off axis circular polarization. Slightly larger than the QFH
Bent turnstile	Adequate zenith gain	Very frequency sensitive

Because of its good pattern qualities, the resonant quadrifilar helix was chosen for further investigation as to techniques for obtaining the needed bandwidth. Physically scaled model antennas operating in S-band (2300 MHz) were fabricated to investigate the affect of element size (diameter or width) on the bandwidth. Large diameter tubing was found acceptable.

A full scale breadboard antenna (QFH No. 1) was constructed from 1/4 inch diameter copper tubing and fed with 1/4 inch diameter semi-rigid coaxial cable. Antenna patterns were measured for this antenna in its normal condition and when it was slightly distorted in shape (reduced in height and somewhat fatter in diameter with the elements kept the same length). The conventional shape yielded acceptable patterns. This model's VSWR bandwidth was slightly too narrow and so 7/8 inch diameter tubing was chosen for the final model's element diameter to achieve the needed bandwidth.

The final designs (QFH No. 2 and QFH No. 3) were fabricated from 7/8 inch diameter tubing and assembled with fiberglassed reinforcing structures. A photograph of antenna Number 2 is shown in Figure 1. A length of UT141 (0.141 inch diameter) semi-rigid coaxial cable was fed through one arm of the antenna to excite the antenna. This is the infinite balun feed technique.

Test data yielded these conclusions:

1. Good pattern coverage at 142 MHz with good circular polarization was obtained with a QFH 14-7/8 inches in diameter and 21 inches in height.

2. Adequate VSWR bandwidth was achieved using antenna elements made from 7/8 inch diameter tubing.

3. Deforming the fullscale breadboard QFH model to a "football" shape degraded the circularity at the horizon.

4. A ground plane is not needed for use with the QFH. Little improvement and some degradation was observed during tests with a ground plane.

5. Light weight final designs were achieved: QFH No. 2 weighed approximately 12 pounds, QFH No. 3 weighed approximately 6.5 pounds.
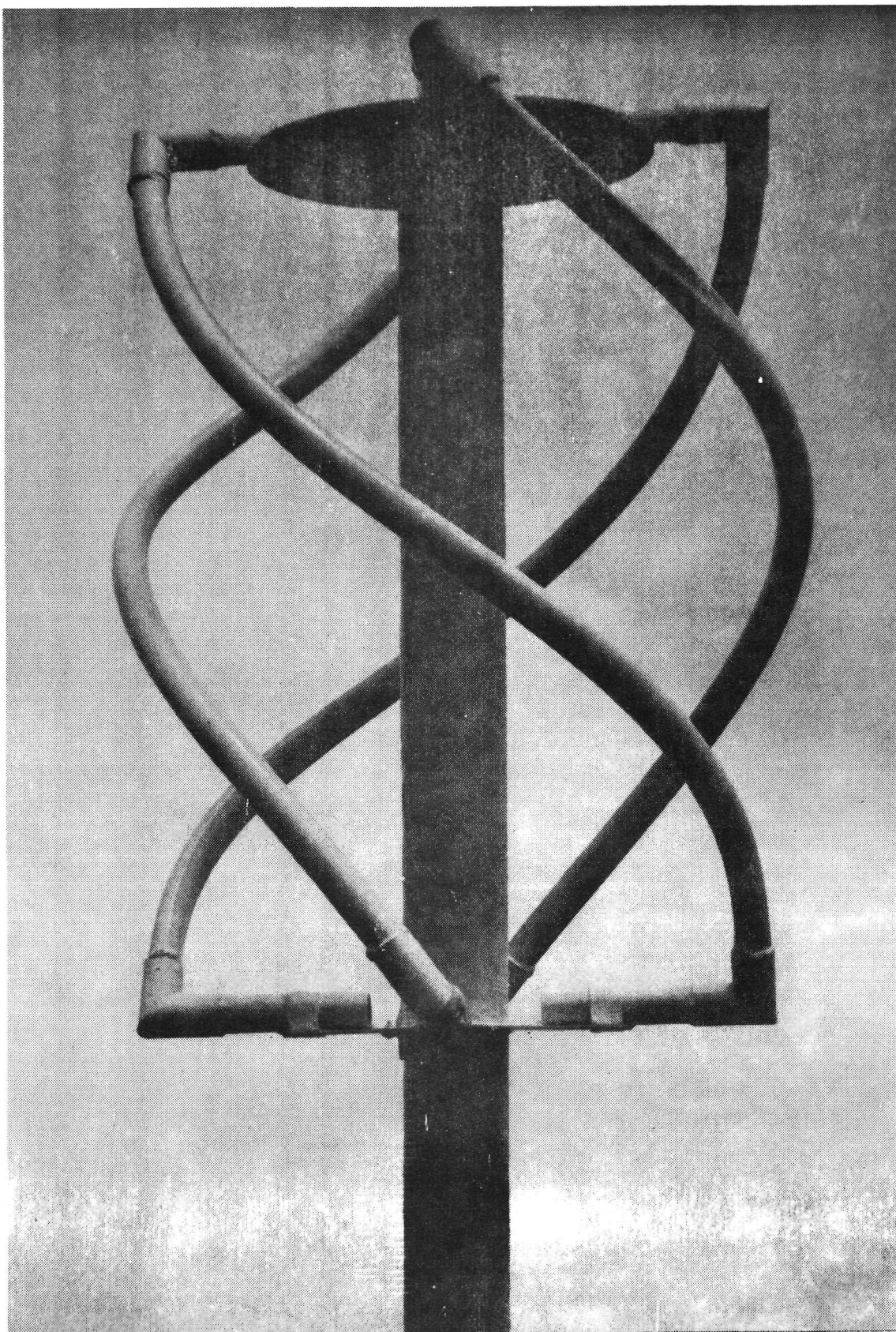
Figure 1. Photograph of Quadrifilar Helix Antenna No. 2.

1.0 ANTENNA DESIGN CONSIDERATIONS

A detailed comparison [1] of the resonant quadrifilar helix with other antennas indicates that it provides an optimum antenna for narrow bandwidth applications requiring a broad beamwidth, cardiod shaped radiation pattern, circular polarization, and compact physical configuration. Feeding two bifilar helices in phase quadrature will produce the cardiod radiation pattern with circular polarization.

A single half-turn, half-wavelength quadrifilar antenna has a nominal gain of 5 dB above a circular isotropic source. The typical resonant impedance of a quadrifilar helix is 40 ohms making it suitable for interface to conventional 50 ohm transmission systems.

Bandwidths of several percent are typical for helices with thin wire elements. As part of the investigation an endeavor was made to observe bandwidth as a function of element diameter.

As with all coaxially fed balanced antennas, the bifilar helix requires a balun. The balun's function is to distribute equal currents of opposite phase from the feeding coax line to the antenna elements. Three accepted balun designs that can be applied to the helix are then folded, split sheath, and the infinite balun. The infinite balun was chosen for its electrical and mechanical simplicity. No additional impedance matching is necessary as the infinite balun causes no impedance transformation. The 90° phasing required for circular polarization is accomplished by making one bifilar slightly capacitive and the other slightly inductive. This is done by making the elements slightly different in length at the resonant frequency.

In addition to the electrical characteristics, mechanical properties were also considered. Since the antenna's residence will be atop a sailboat mast; weight, effective sail area, and structural integrity are of concern.

1.1 Model Antennas Investigated

Quadrifilar helix No. 2 antenna weighed slightly over 12 pounds while quadrifilar helix No. 3 weighed 6.5 pounds. The weight reduction was achieved through the use of aluminum tubing instead of the copper tubing used in QHF No. 2. The effective horizontal sail area of both antennas was 1.4 square feet which will produce a maximum wind loading of 35 pounds in an 80 mph wind. The antenna's arms were attached on the top and bottom to a 2-1/2 inch epoxy-fiberglass tube which provided the assembly's integral support structure.

In an attempt to increase the bandwidth of a quadrifilar helix antenna, scale models were fabricated on styrofoam mandrels and operated at S-band. These are shown in Figure 2. It was observed that bandwidth was directly related to element size. For the final design, "thick" arms were constructed from 7/8" OD tubing. A greater bandwidth might be realized by using wider elements but the corresponding increase in sail area would be a mechanical problem.

Previous research [2] has shown that greater horizon coverage can be achieved by fabricating multiturn helices with high length-to-width ratios. At VHF frequencies, a typical multiturn helix would be over 10 feet in length and would be an unacceptable fixture atop a sailboat mast. The patterns from these antennas exhibit very low back lobes which could be undesirable if the vessel was heeling and attempting to communicate with a satellite to windward.

A fullscale breadboard antenna (QFH No. 1) was fabricated by bending three 1/4" copper tubing arms and one 1/4" semi-rigid coaxial arm around a mandrel. This antenna is shown in Figure 3 without a ground plane and in Figure 4 with a ground plane. The coaxial cable served both as one arm of the helix and RF feed to the top of the antenna. Swept frequency VSWR data are shown in Figure 5. Figure 6 shows the antenna pattern.

A four element 1/4 wave ground plane was positioned at various distances behind the base of QFH No. 1 to investigate ground plane effects. Antenna patterns measured for ground plane spacings between 0 and 17 inches are shown in Figures 7 to 11.

The antenna shape was distorted by reducing the overall height and increasing the diameter as shown in Figure 12. Antenna patterns were then taken with and without a ground plane. Figures 13 and 14 show the typical pattern changes.
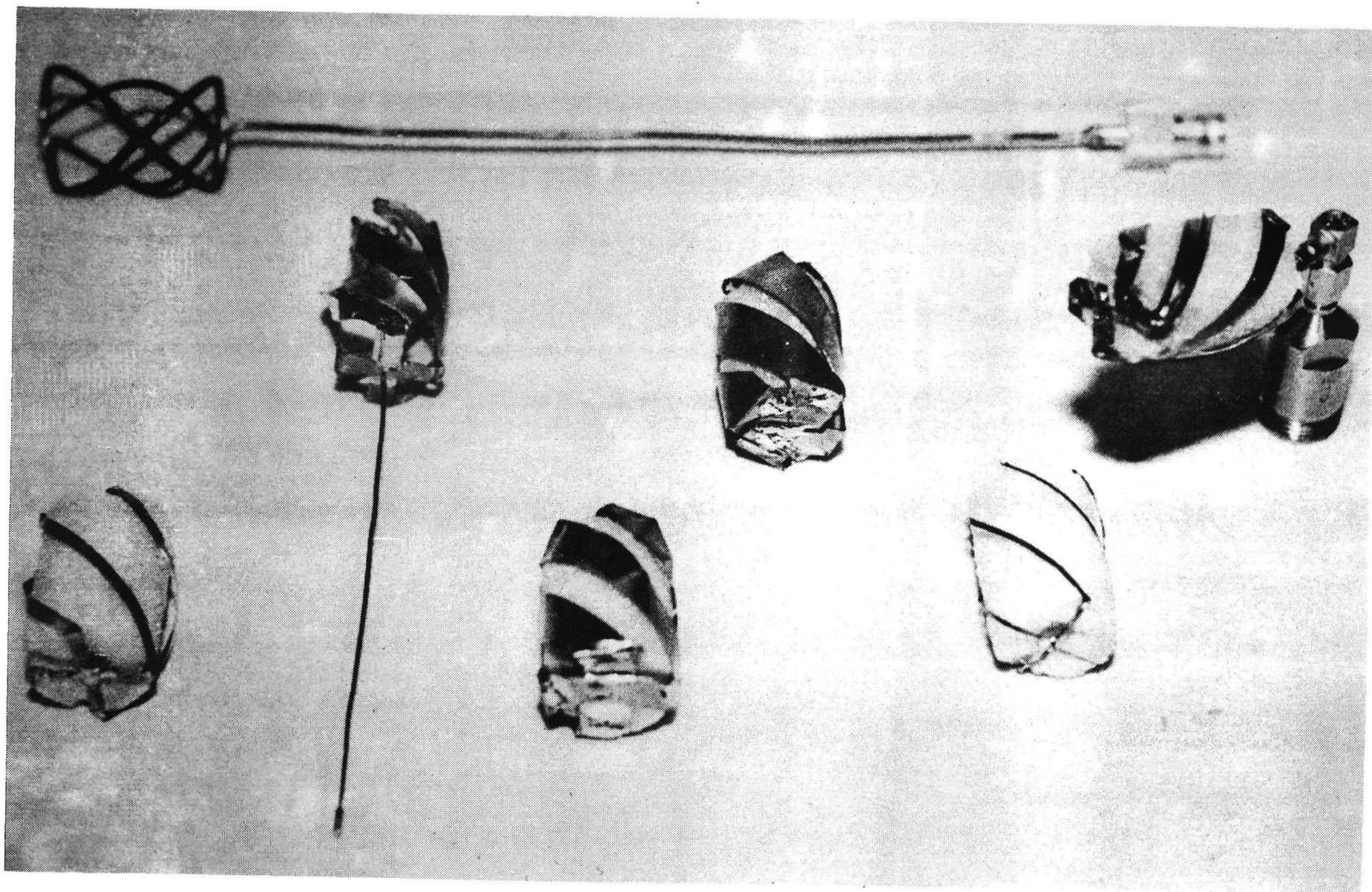
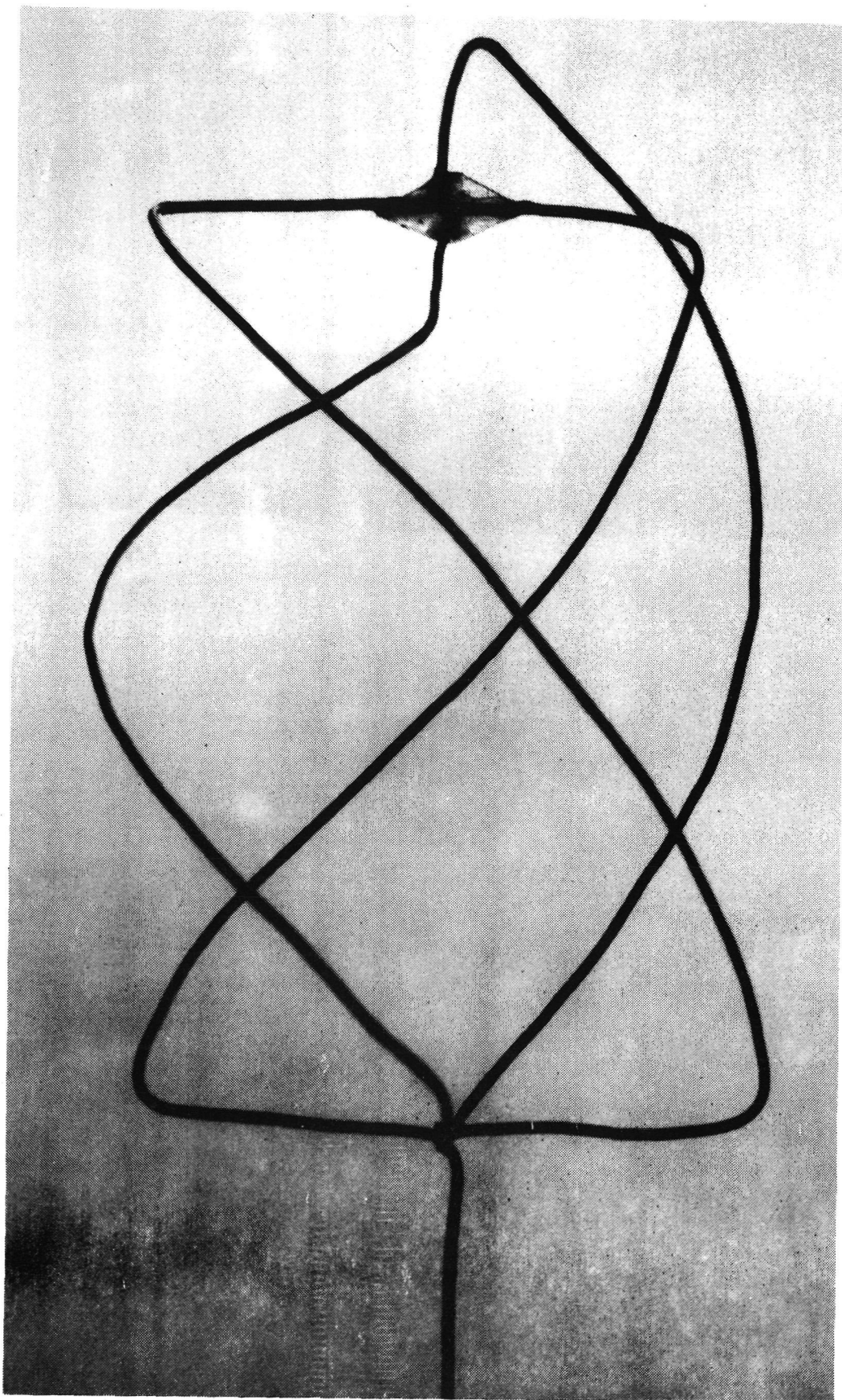Figure 2. Photograph Of The Reduced Size QFH Scaled For S-band Operation.

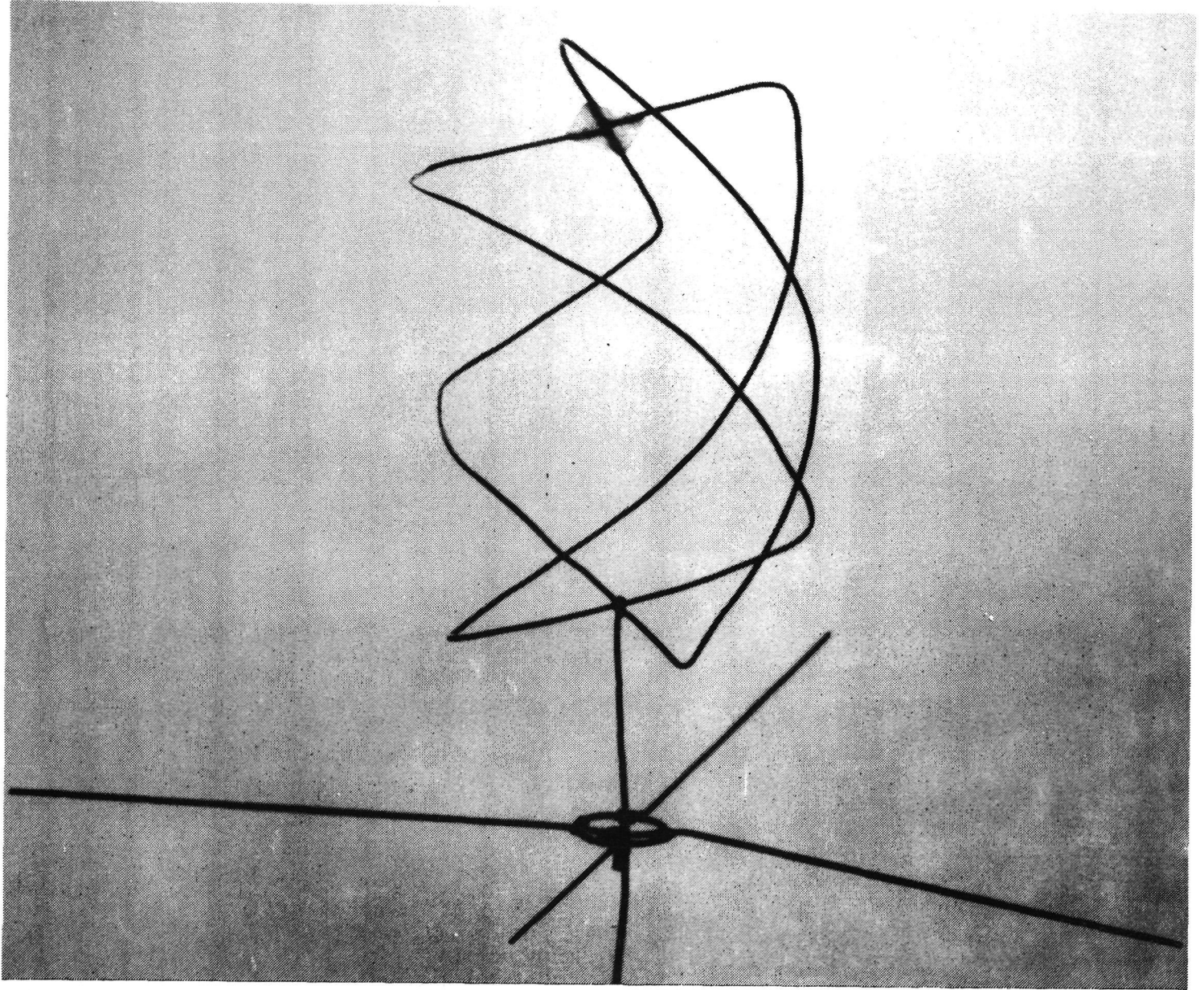Figure 3.   Photograph Of QFH No. 1 Without The Ground Plane.

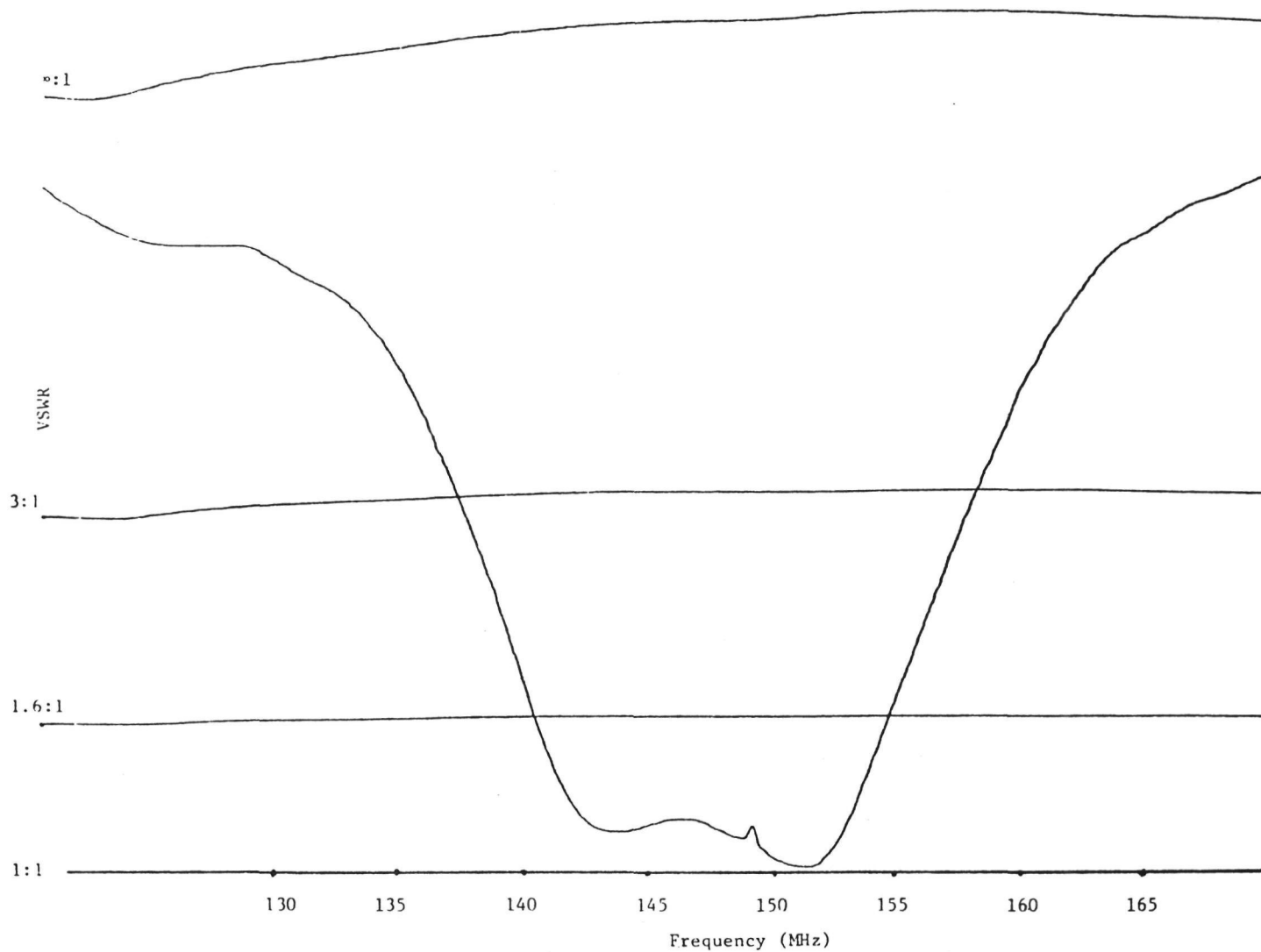Figure 4.   Photograph Of QFH No. 1 With Ground Plane.

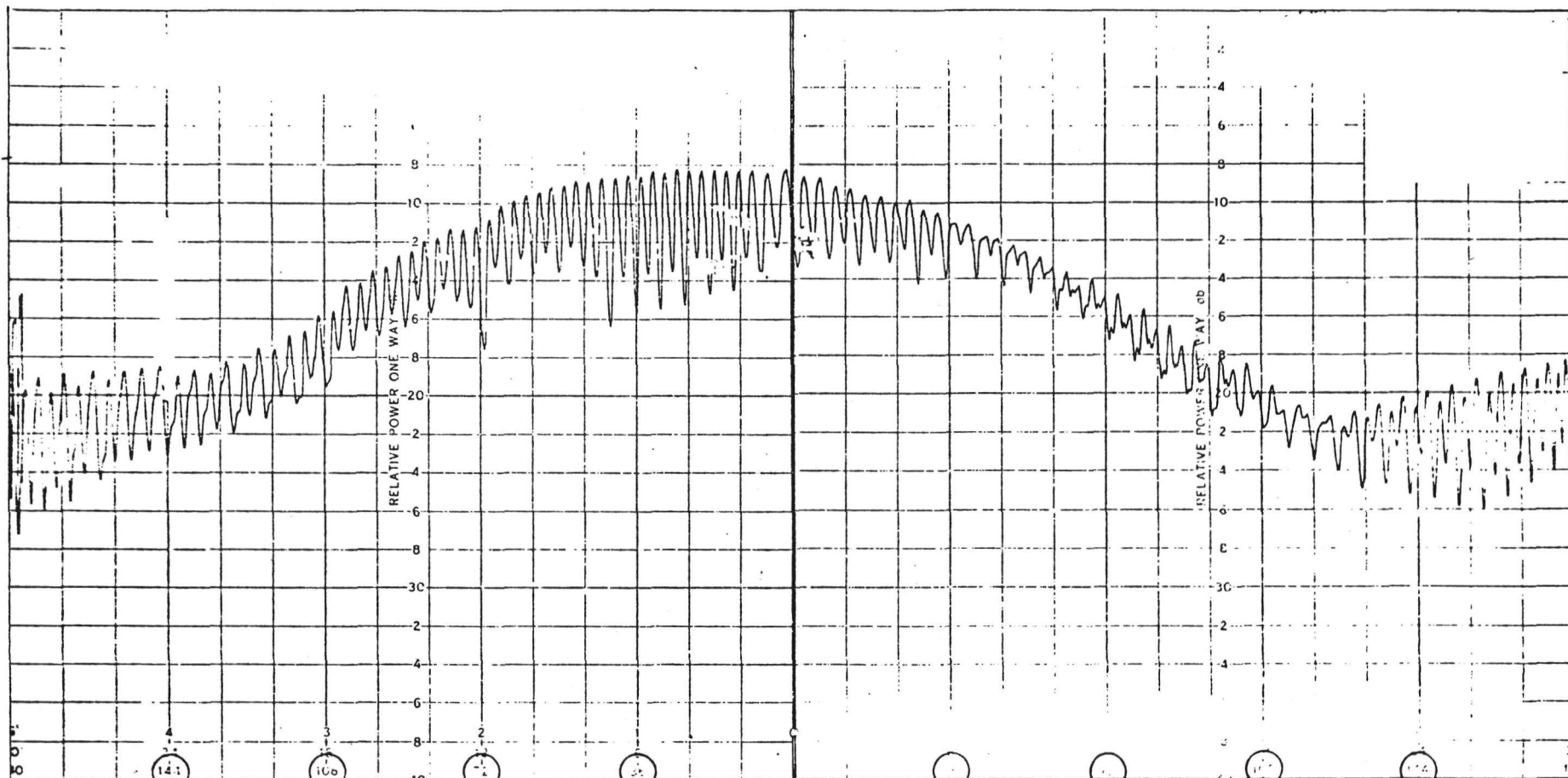Figure 5.   VSWR Plot For Quadrifilar Helix No. 1.

Figure 6.   QFH Antenna No. 1 Antenna Pattern.   φ = 0° Plane,
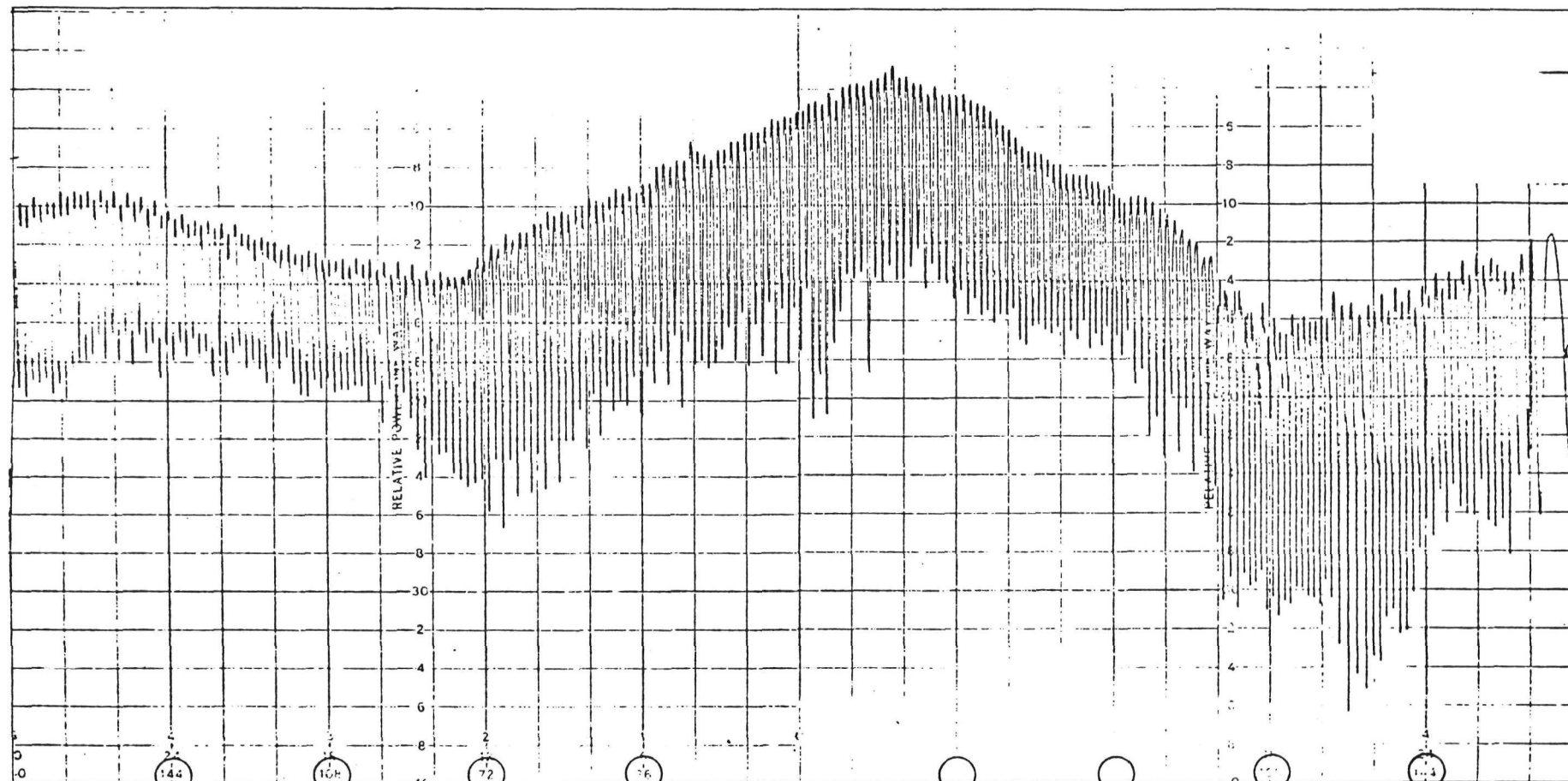Rotating Linear Polarization, 142 MHz, No Ground Plane.

Figure 7. QFH Antenna No. 1 Antenna Pattern. φ = 0° Plane, Rotating Linear
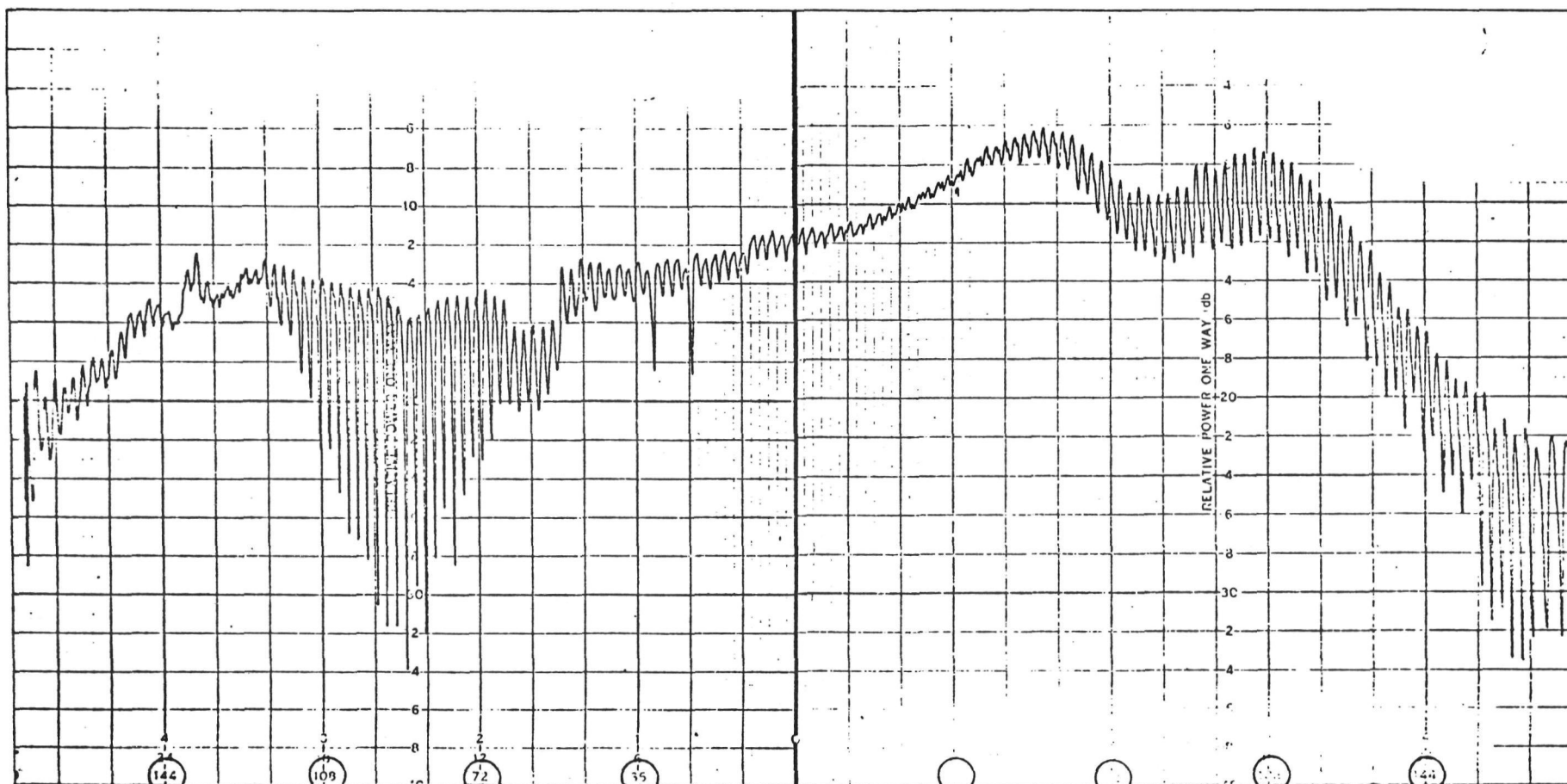Polarization, 142 MHz, Ground Plane Positioned Against Base of Antenna.
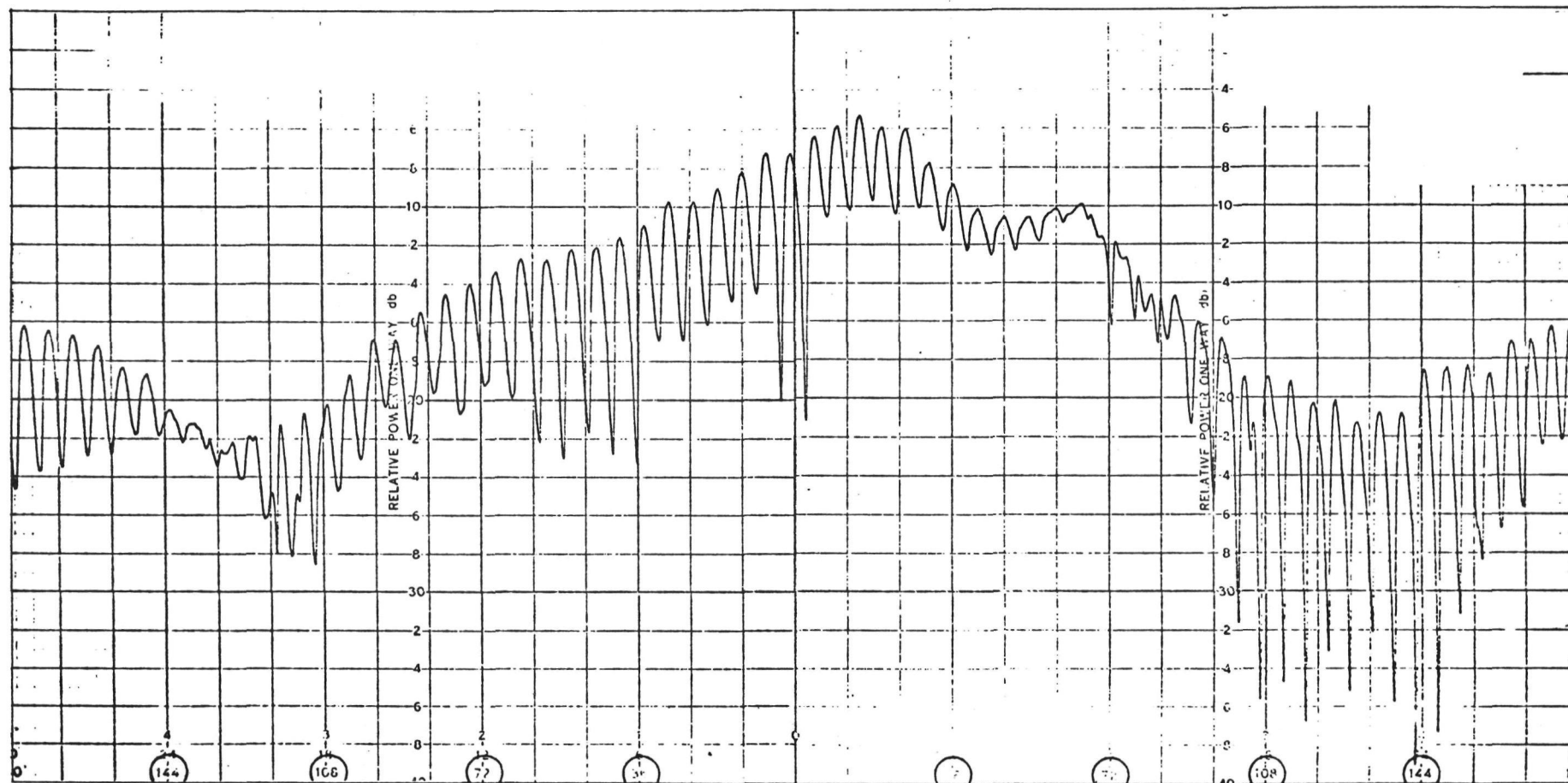
Figure 8. QFH Antenna No. 1 Antenna Pattern. $\phi = 0°$ Plane, Rotating Linear
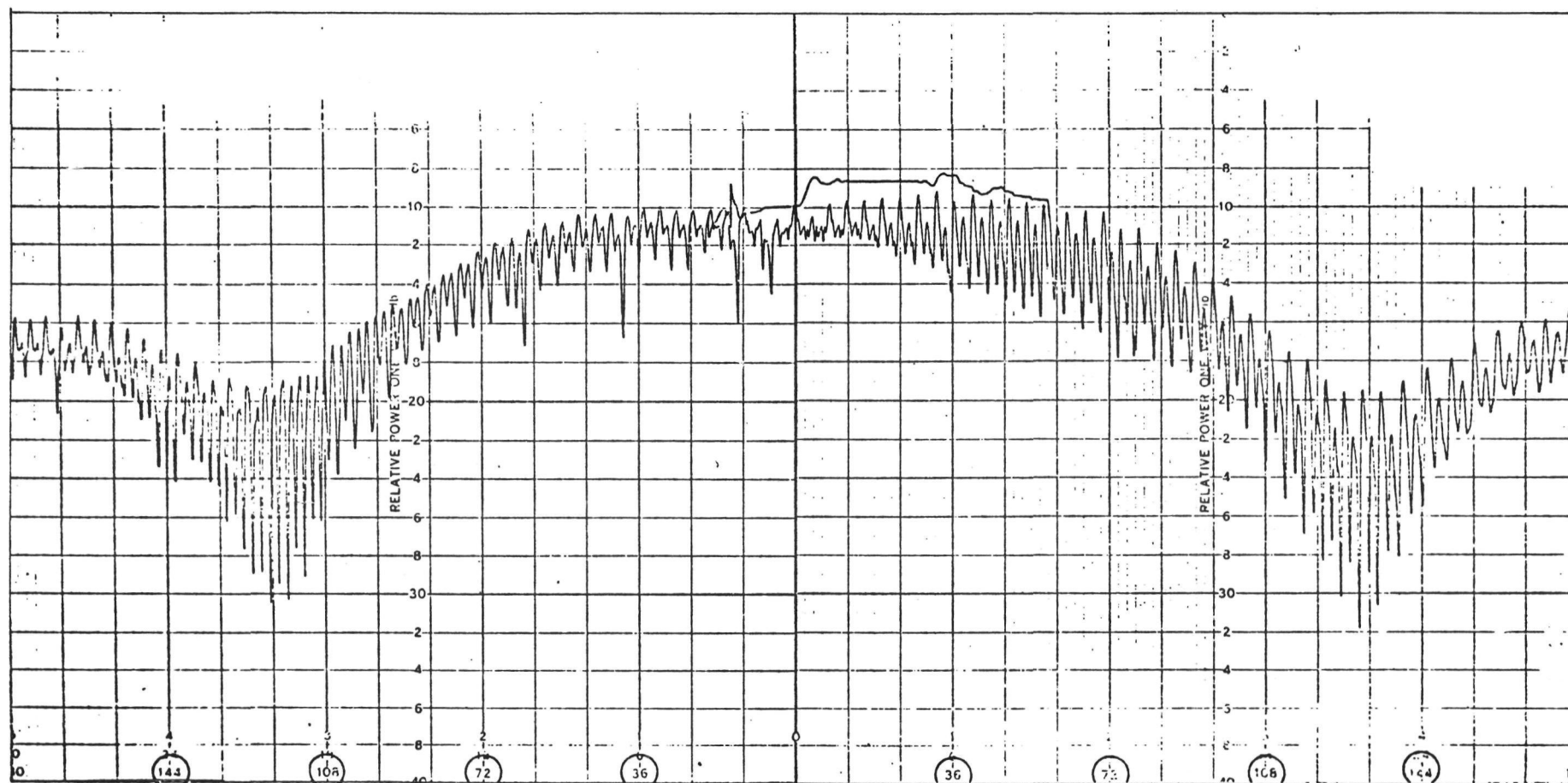Polarization, 142 MHz, Ground Plane Positioned 6" From Base of Antenna.

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B-19
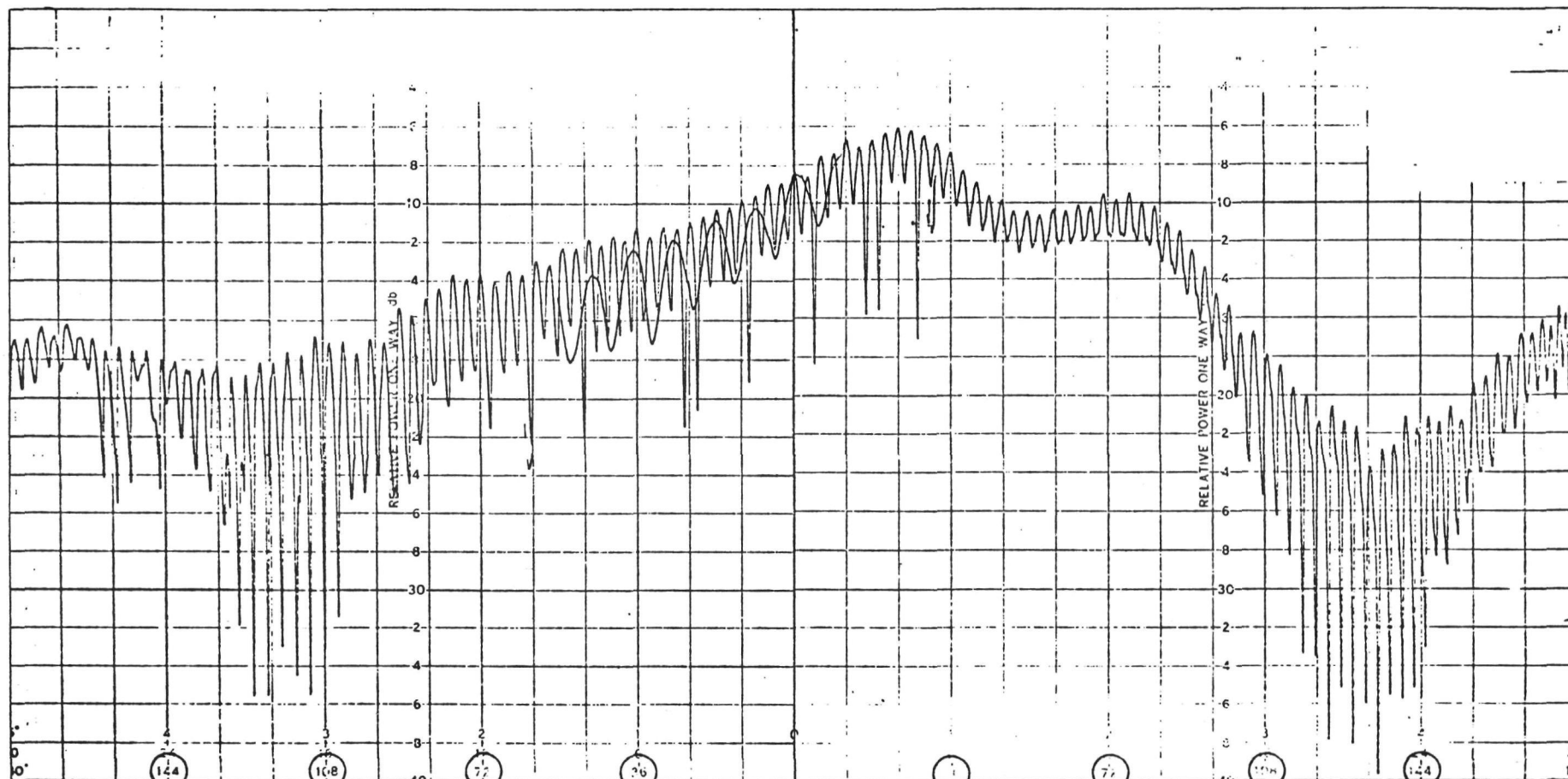
Figure 9. QFH Antenna No. 1 Antenna Pattern. φ = 0° Plane, Rotating Linear
Polarization, 142 MHz, Ground Plane Positioned 9" From Base of Antenna.

Figure 10.   QFH Antenna No. 1 Antenna Pattern. $\phi = 0°$ Plane, Rotating Linear
Polarization, 142 MHz, Ground Plane Positioned 15" From Base of Antenna.

Figure 11. QFH Antenna No. 1 Antenna Pattern. $\phi = 0°$ Plane, Rotating Linear Polarization, 142 MHz, Ground Plane Positioned 17" From Base of Antenna.
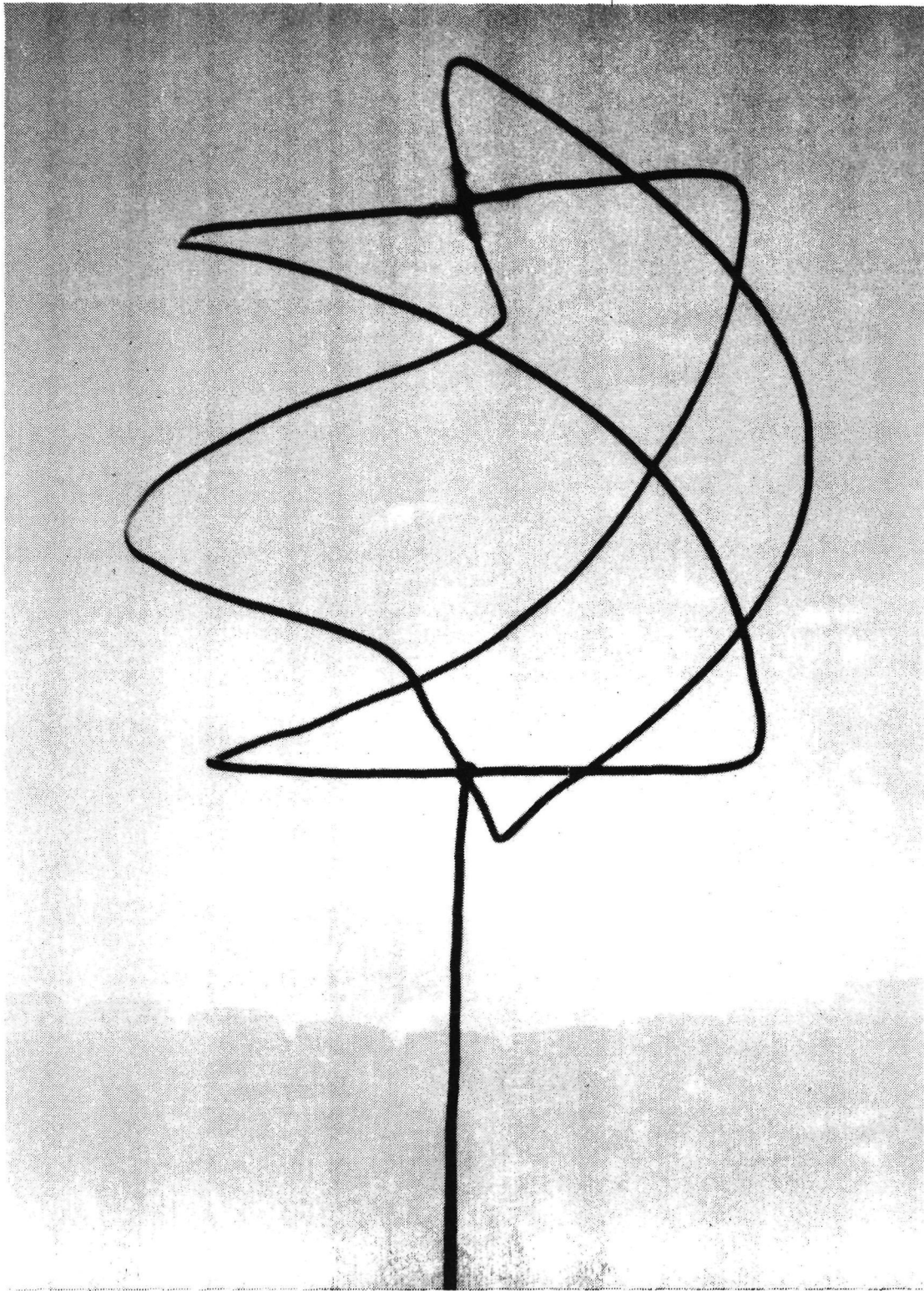
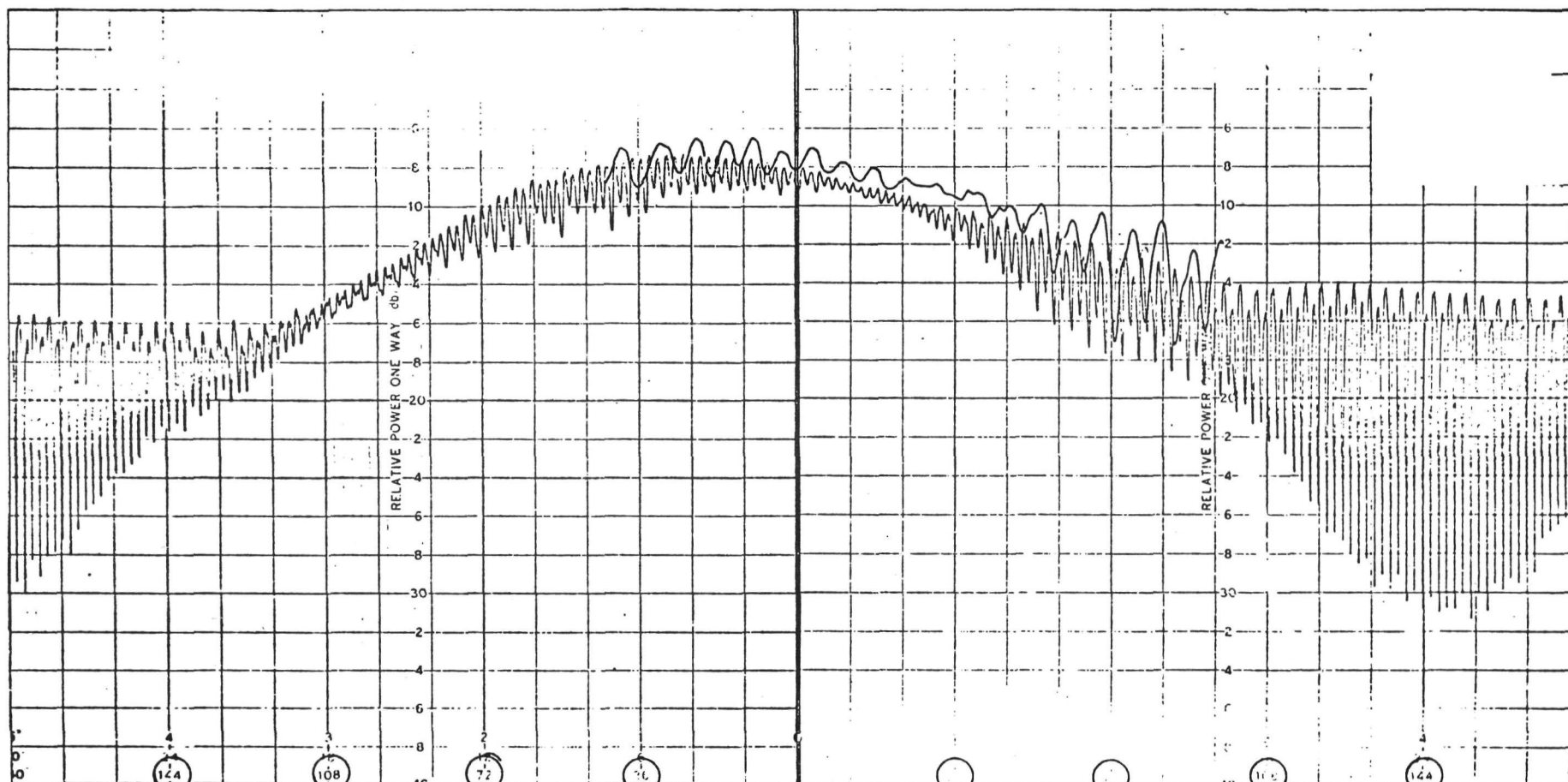Figure 12. Photograph of Quadrifilar No. 1 Distorted to a "Football" Shape.

Figure 13.   QFH Antenna No. 1 Antenna Pattern.   φ = 0° Plane, Rotating Linear
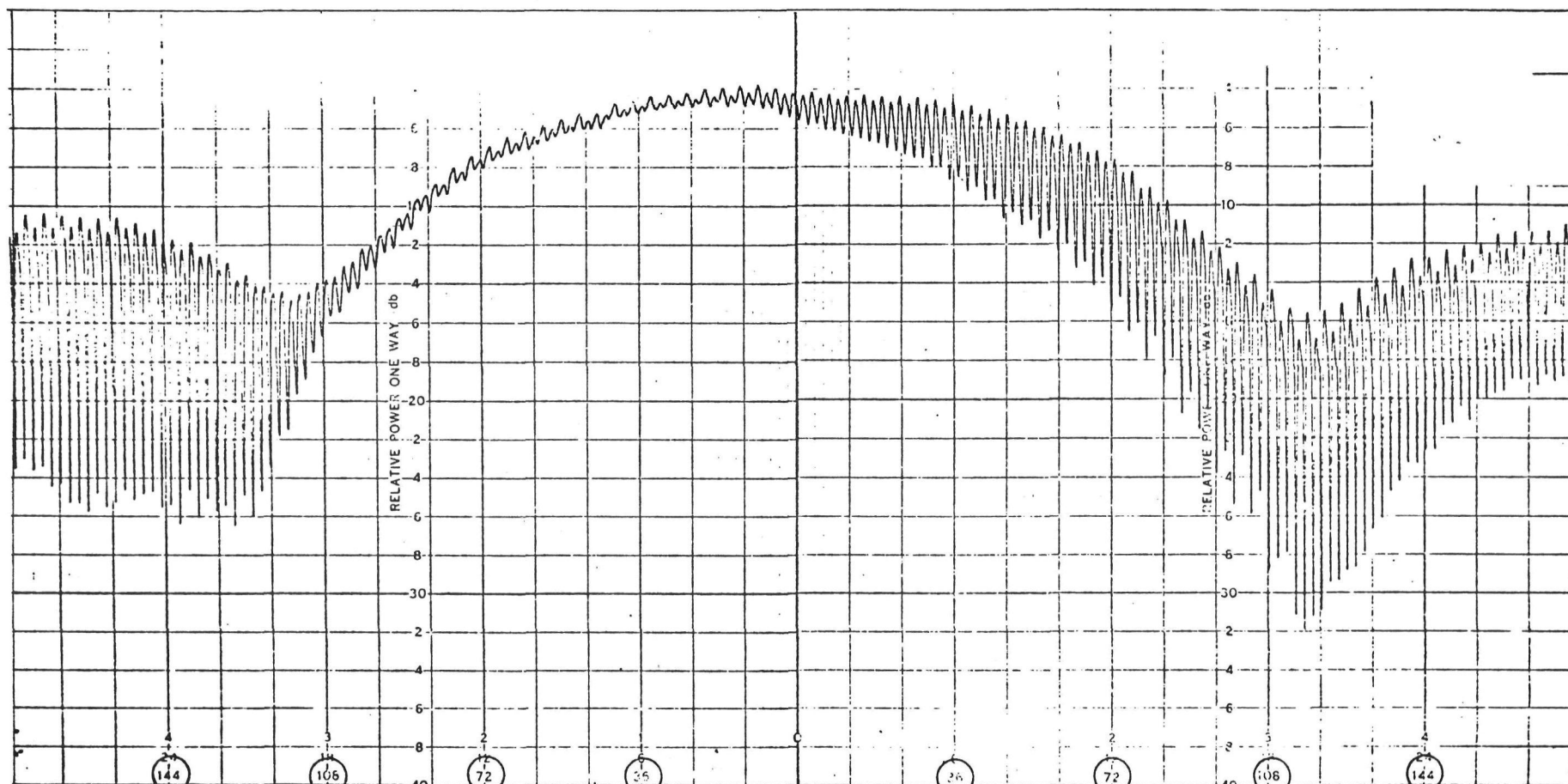Polarization, 142 MHz, Overall Length Reduced and Diameter Increased,
No Ground Plane.

Figure 14.   QFH Antenna No. 1 Antenna Pattern. $\phi = 0°$ Plane, Rotating Linear
Polarization, 142 MHz, Overall Length Reduced and Diameter Increased,
Ground Plane Positioned 17" From Volute Base.

2.0 MECHANICAL DESCRIPTION OF THE FINAL ANTENNAS

2.1 Quadrifilar Antenna No. 2

The quadrifilar antenna No. 2 (See Figures 15, 16 and 17) was designed
to be fabricated from 7/8" diameter 0.045" wall copper tubing which was formed
with special tooling, as shown in Figure 15, into four 180° helices with a pitch
of 41 inches. Two pitch diameters were used: one is 14 inches and the
other is 15-1/4 inches. The four individual 180° helices were cut to achieve
a 20-1/2 inch overall height and assembled with 90° copper elbows and straight
sections of copper tubing to form the four radiating elements of the antenna.
A 9-1/2 inch diameter by 3/16 inch thick fiberglass disc is located at the top
of the antenna to locate the four radiating elements at 90° increments and
also maintain the 0.25 inch gap and centering of the coaxial feed point. An
8 inch diameter by 1/16 inch thick scalloped brass disc is located at the bottom
of the antenna to maintain the 90° increments of the radiating elements as well
as to act as an electrical interconnection between all four of the radiating
elements. The entire antenna assembly is mounted on a filament wound section
of fiberglass pipe of 2 inch nominal diameter and an overall length of 42 inches.
This pipe acts as the main structure member of the entire antenna assembly.
Semi-rigid coax is located inside of one of the radiating elements with a single
UHF female bulkhead-mounted connector in the scalloped brass disc located at the
base of the antenna. All metal-to-metal joints were soldered at final assembly
to maintain electrical continuity. Interfaces between the fiberglass pipe,
fiberglass disc, and other metallic surfaces were reinforced with fiberglass
cloth and epoxy resin and the entire unit is given a final paint finish with
epoxy spray enamel. The final weight of the entire unit is 12 pounds.

2.2 Quadrifilar Antenna No. 3

The design of quadrifilar antenna No. 3 is basically the same as No. 2
with the exception that weight was given major consideration, which resulted in
the following modification in the design:

1) The radiating elements helix and straight sections are formed from
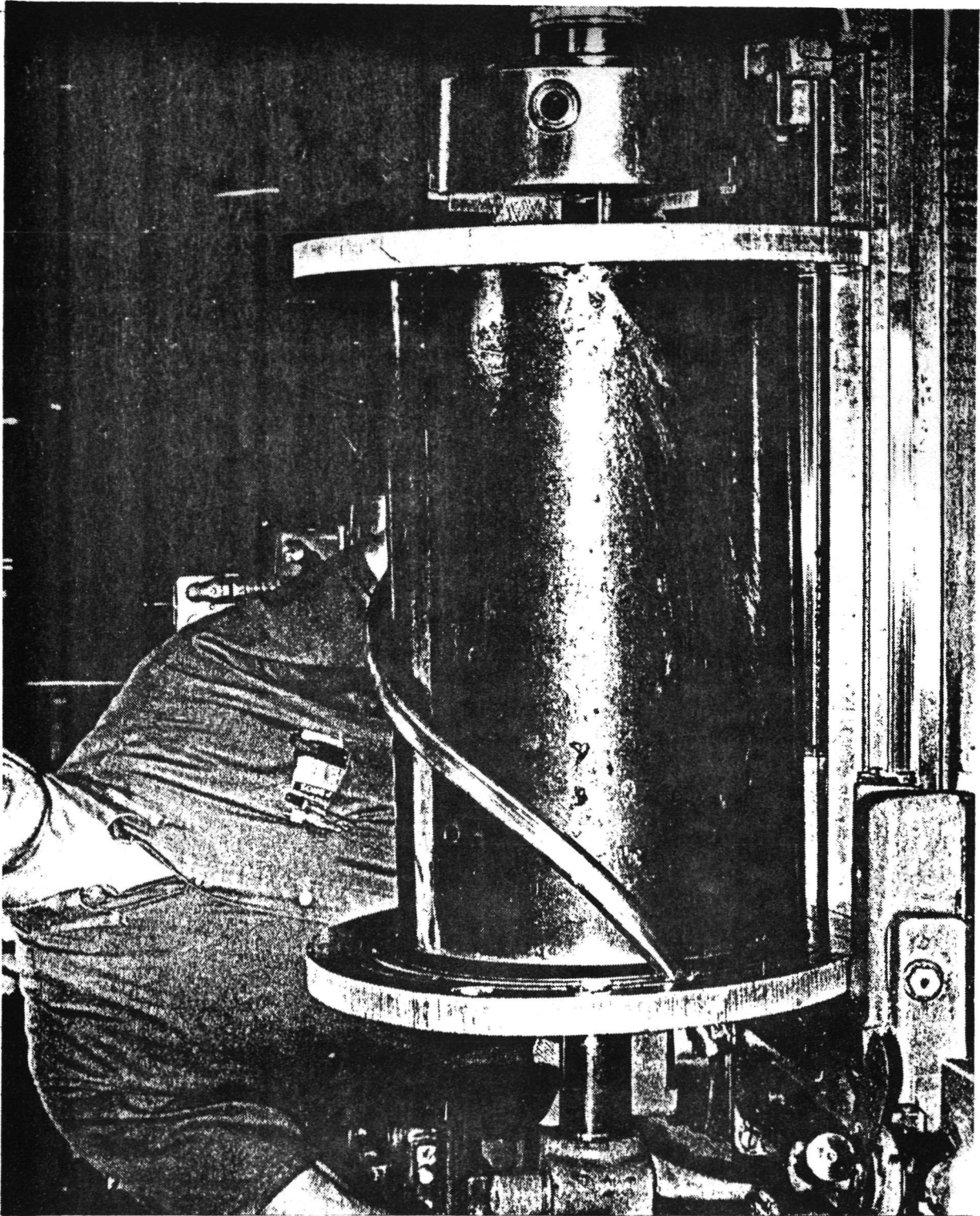   7/8 inch outside diameter by 0.049 inch wall, alloy 3003H14, aluminum
    tubing.

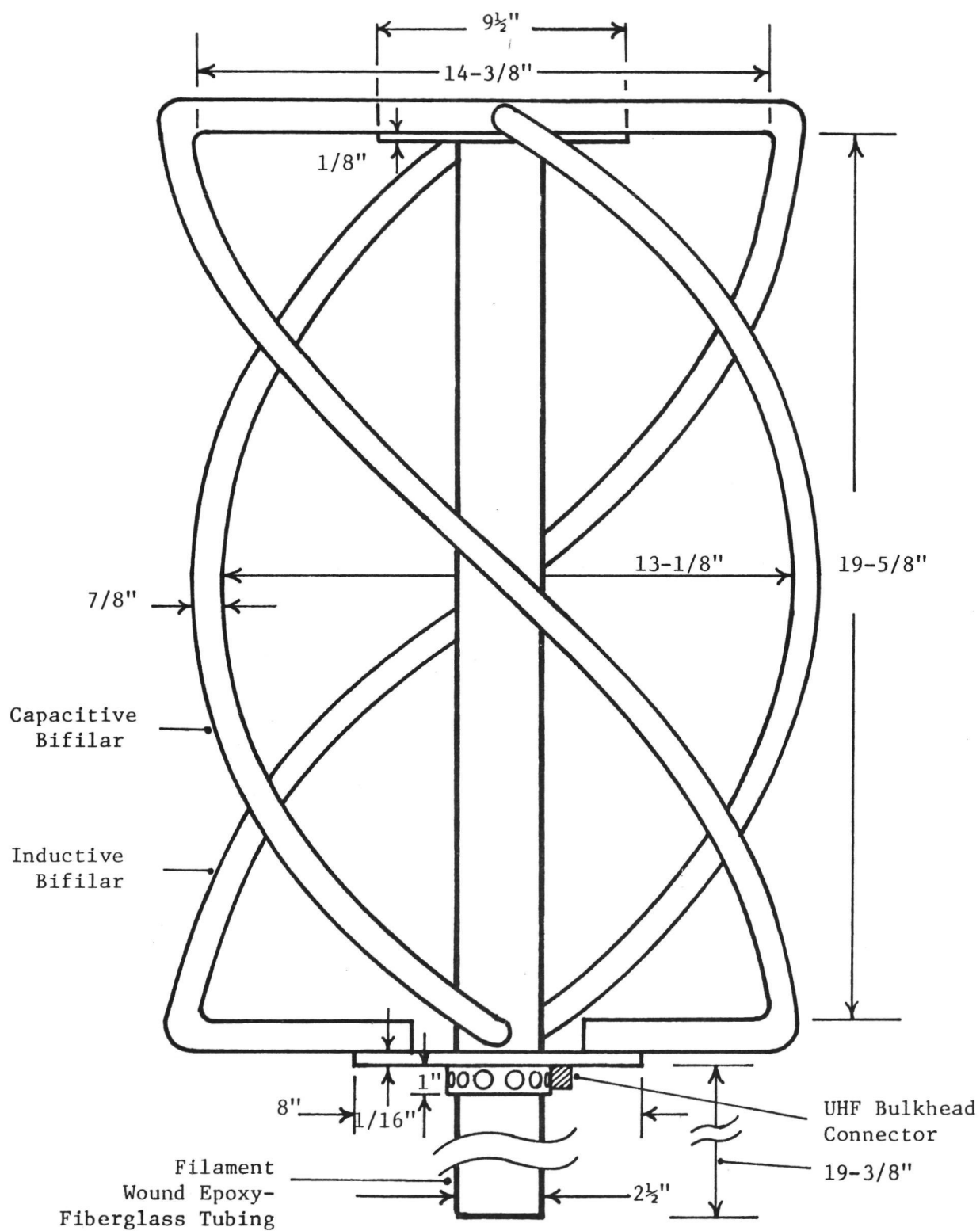Figure 15. Quadrifilar Helix No. 2 In Manufacturing Fixture.

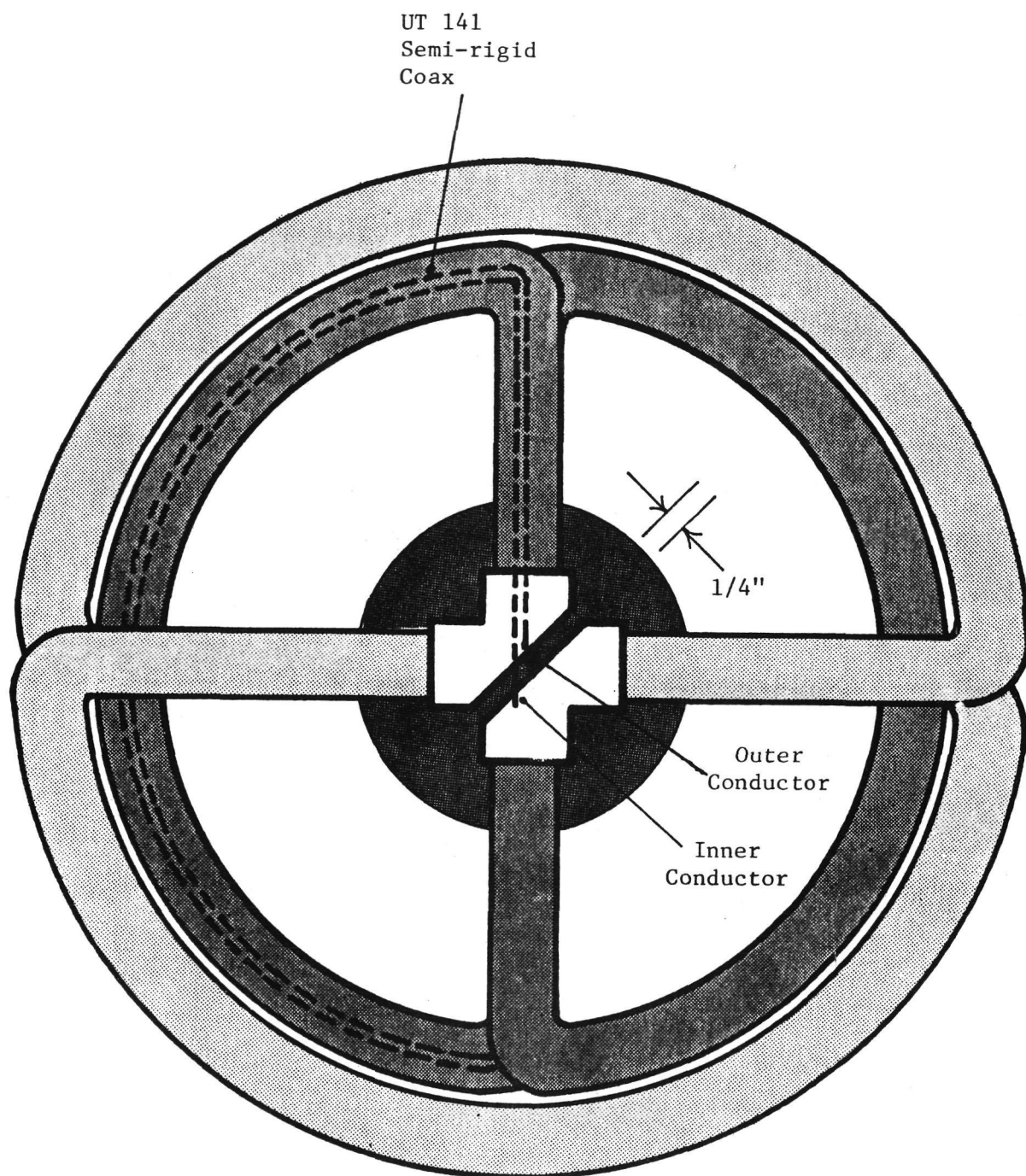Figure 16. Side view (with Dimensions) of Quadrifilar Helix Numbers 2 and 3.

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UT 141
Semi-rigid
Coax

1/4"

Outer
Conductor

Inner
Conductor

Figure 17. Top view of Quadrifilar Helix Numbers 2 and 3

2) The 90° elbows are fabricated from 1.0 inch outside diameter by 0.058 inch wall, alloy 3003H14 aluminum tubing.

3) The lower 8" diameter scalloped interconnecting plate is fabricated from 0.090" thick, alloy 6061-T6, aluminum sheet.

4) All metal-to-metal joints are rigidized by Heli-arc welding to maintain electrical conductivity as shown in Figure 18.

5) The entire aluminum assembly is anodized coated for ultimate weather protection with an epoxy paint overcoat as described in Appendix A.

6) The upper 9-1/2 inch diameter fiberglass disc is perforated for weight reduction.

7) The amount of fiberglass epoxy coating is minimized consistent with structural integrity, to minimize weight.

The above design modification resulted in an overall weight reduction of 5.5 pounds to a final weight of unit No. 2 of 6.5 pounds.

2.3 Other Mechanical Parameters

STRENGTH

The wind force on a solid surface is computed by the formula:

$$F = 1.55 \ PA \left(\frac{520}{T}\right)^{0.4} = 35 \text{ pounds}$$

where:

F = force in pounds

P = pressure in pounds per square foot due to wind velocity = 16 pounds. See Figure 19.

A = projected area in square feet = 1.4 square feet

T = temperature in degrees Rankine = °F + 459.72 = 529.72

The antenna assembly was affixed in a cantilever support and loaded with 35 pounds; the total deflection was 7/8 inches.

FEED DESCRIPTION

Semi-rigid coaxial cable is used to feed the QFH. UT 141 (Uniform Tubes Co. nomenclature) 50 ohm coax, 0.141 inches in diameter is used. Figure 20 presents the loss and power handling capacity of this cable. The cable capacity greatly exceeds the 300 watts power rating desired.

MASTHEAD MOUNTING CONFIGURATION

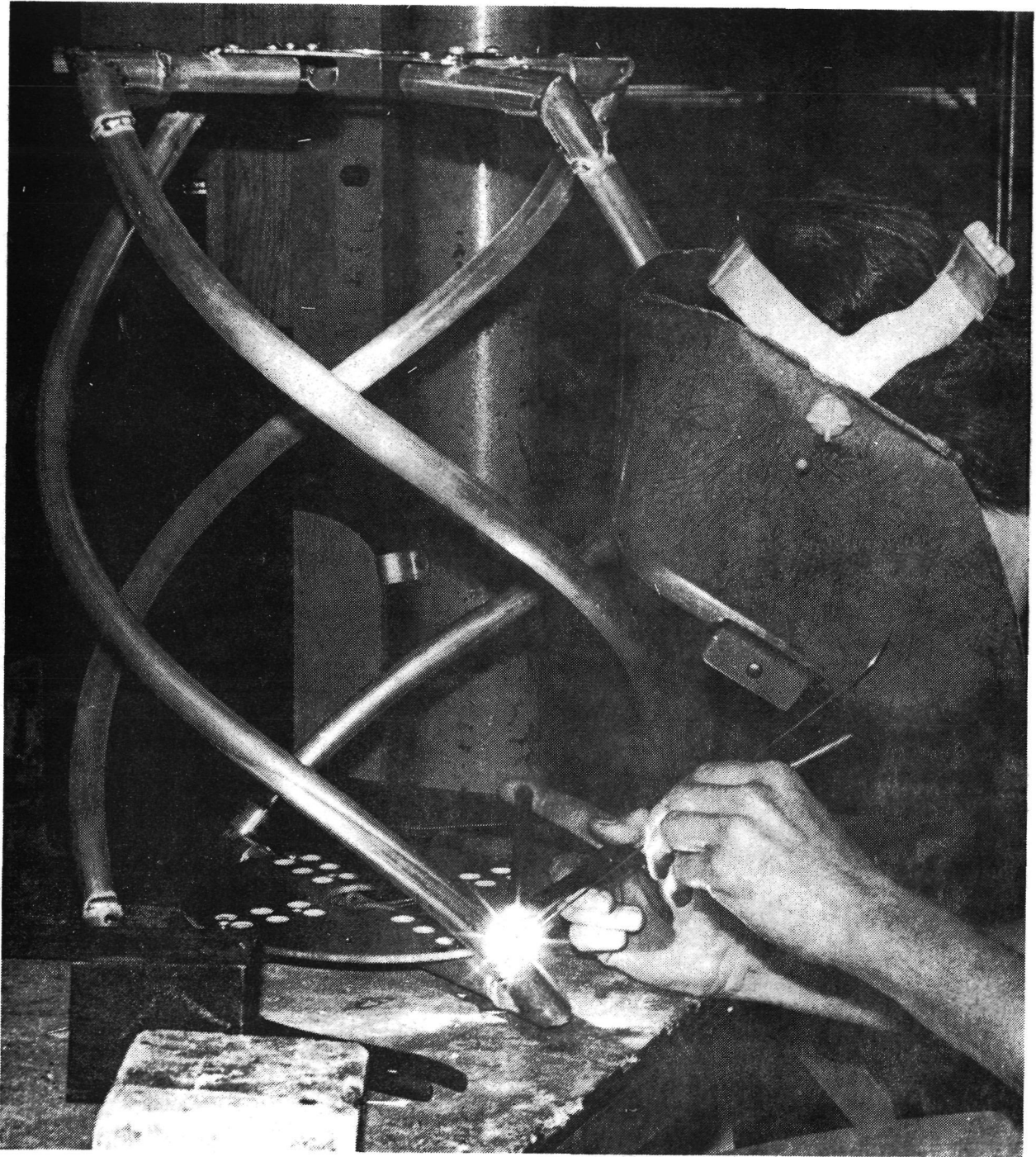The preferred masthead mounting position is sketched in Figure 21.

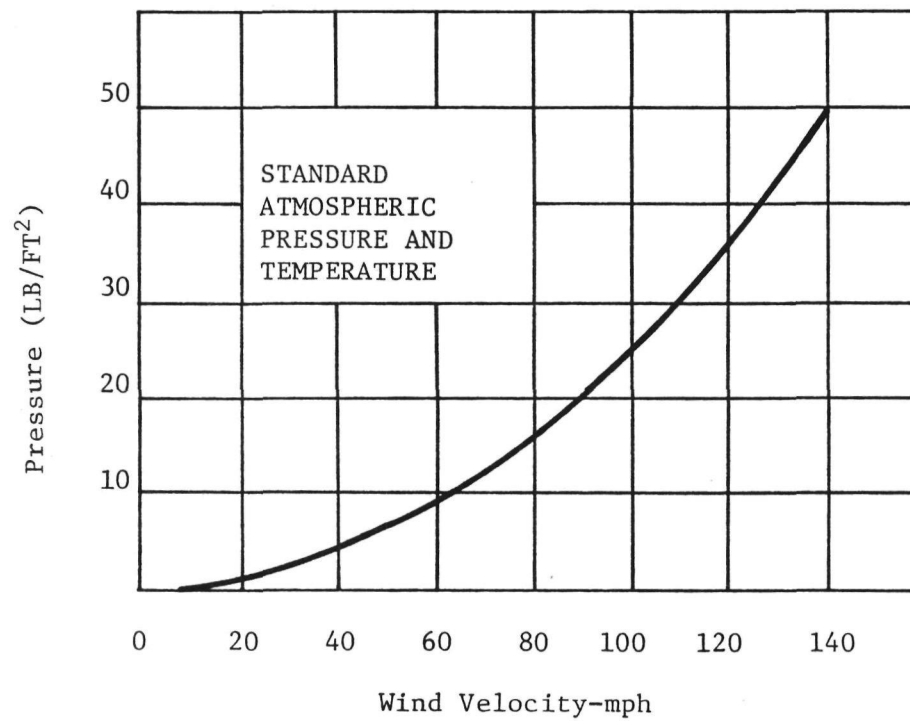Figure 18. Heliarc Welding of QFH Antenna No. 3.
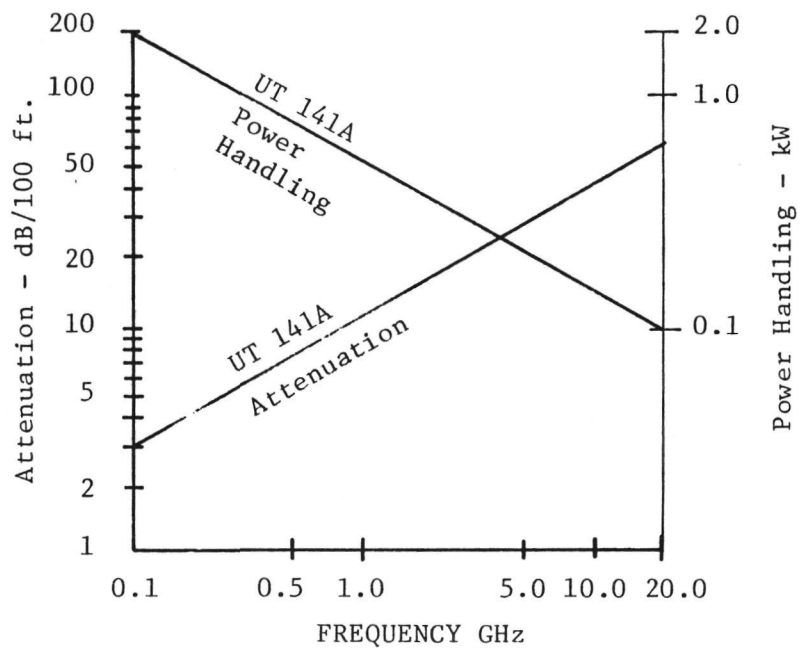
Figure 19.   Wind Pressure vs. Wind Velocity

Figure 20. Attenuation And Average Power
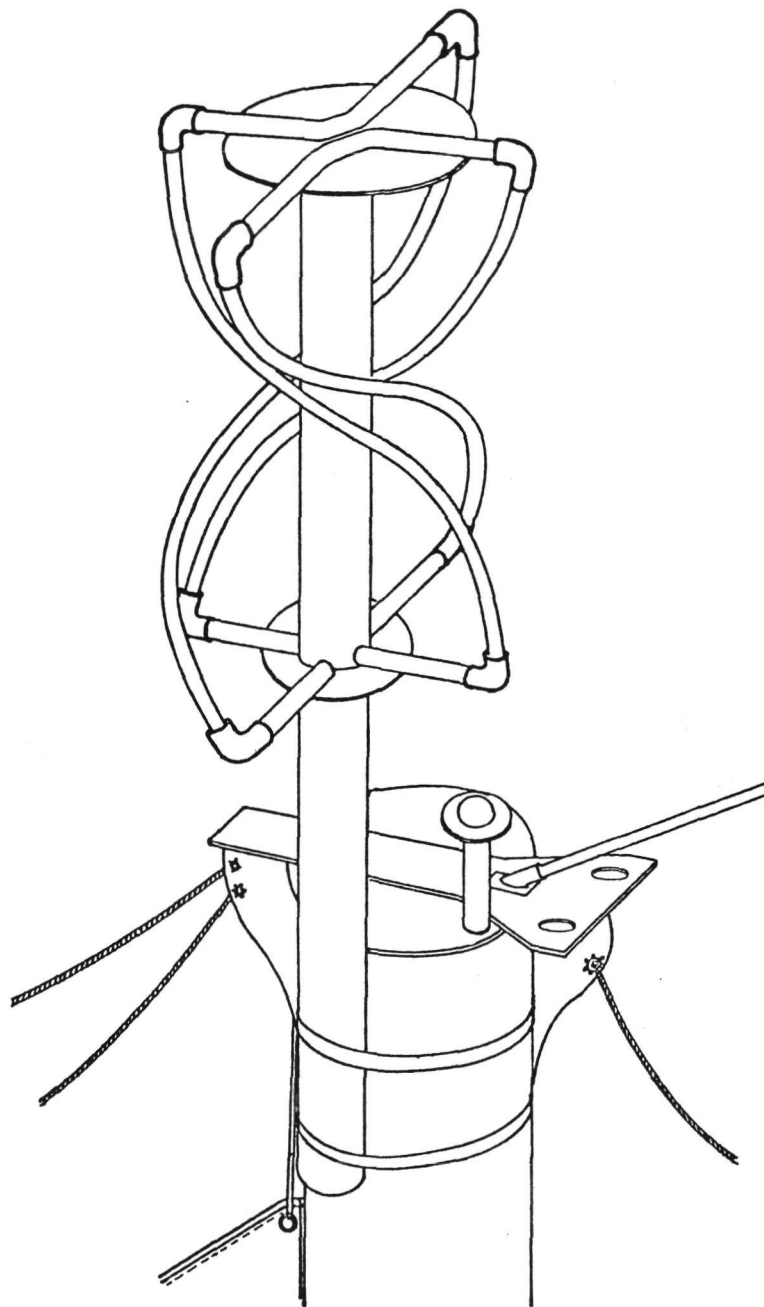Handling for UT 141, 50 ohm Coax.

Figure 21.   Preferred Masthead Mounting Configuration

3.0   TESTING OF THE FINAL MODELS

All final test data including patterns were obtained on Georgia Tech's elevated outdoor antenna range. This range is sketched in Figure 22. Antenna pattern measurements utilized a medium gain 4 element Yagi antenna as the transmitter. The Yagi used was Cushcraft Model 147-4, a tunable gamma matched aluminum antenna. The gamma match was optimally tuned to 142 MHz using swept frequency techniques. Data on this antenna are included in Appendix A. The Yagi was mounted on a variable speed rotating pedestal and fed through a Sage Laboratories Model 305W rotary joint. The RF source was a Hewlett Packard 608 signal generator with frequency measurements made with a Hewlett Packard 5303 frequency counter.

The pattern recordings were made using a Scientific Atlanta 1750 receiver. The antenna pedestal supporting the antenna being tested, utilizes 3 axes; one axis orients the antenna coordinates downward by the 6 degrees depression angle to the transmitter. The remaining two axes are used for measurements.

Even though the antenna patterns were made with a narrow band superheterodyne receiver, severe interference was observed with local radio traffic in the Atlanta area, as a result measurements on some frequencies in the 135 to 149 MHz bands could not be made.

Antenna patterns for QFH Numbers 2 and 3 are shown in Figures 23 to 27 using pattern coordinate geometry in Figure 28. VSWR plots of these antennas are shown in Figures 29 and 30.

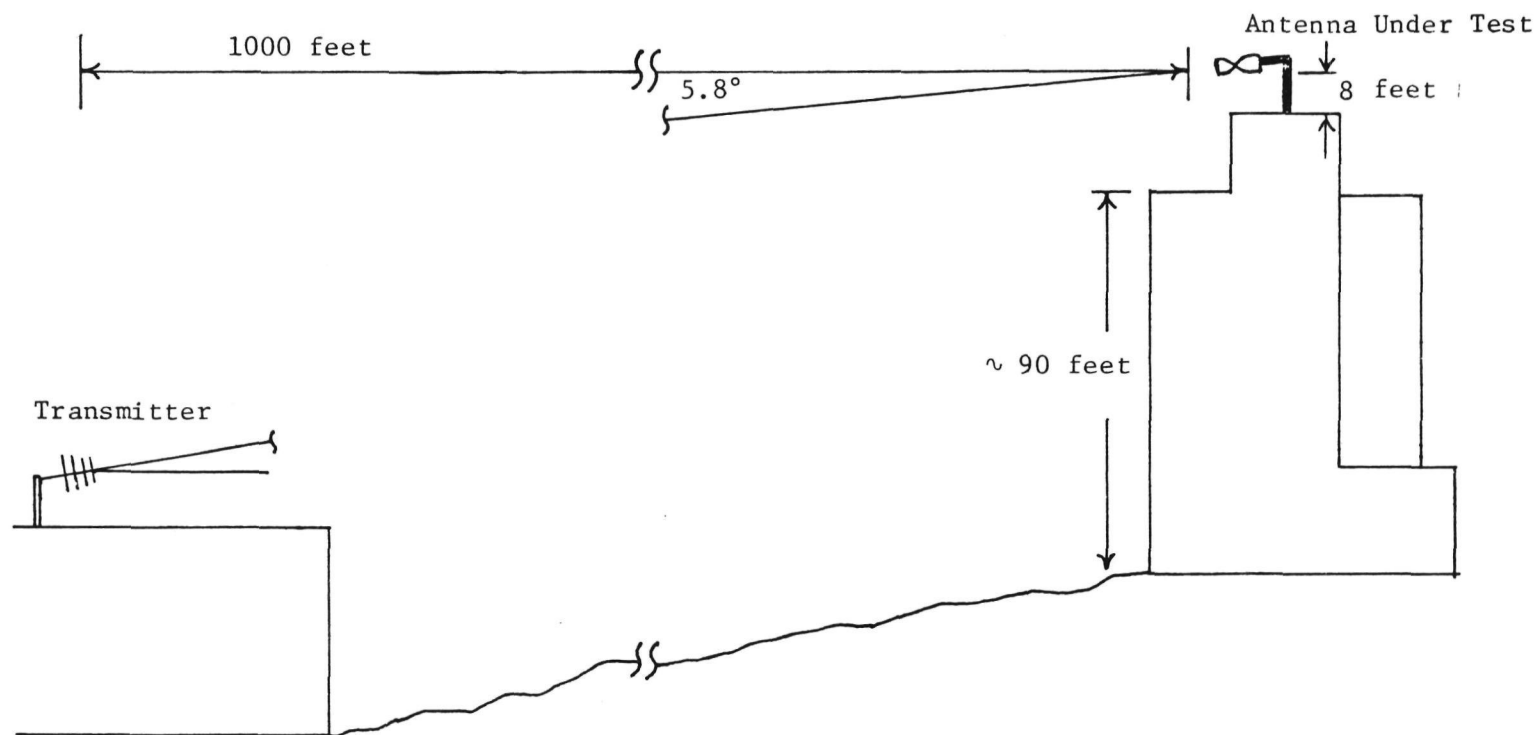Table 3 presents a summary of test results for the final antenna models.

Figure 22. Sketch of Georgia Tech's 1000 Foot Elevated Antenna Range.
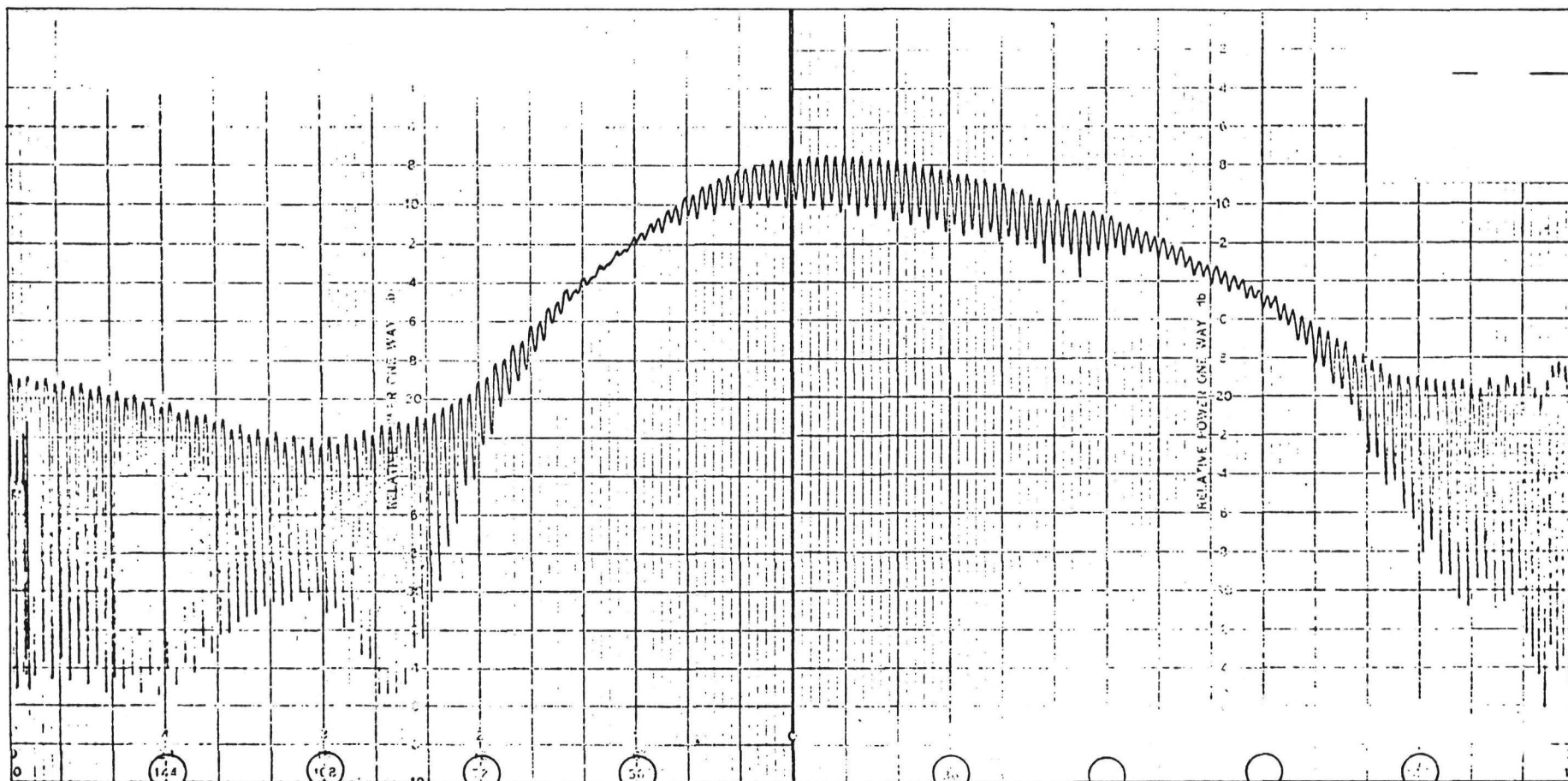
Figure 23.   QFH Antenna No. 2 Antenna Pattern.   ϕ = 0° Plane,
Rotating Linear Polarization, 142 MHz.

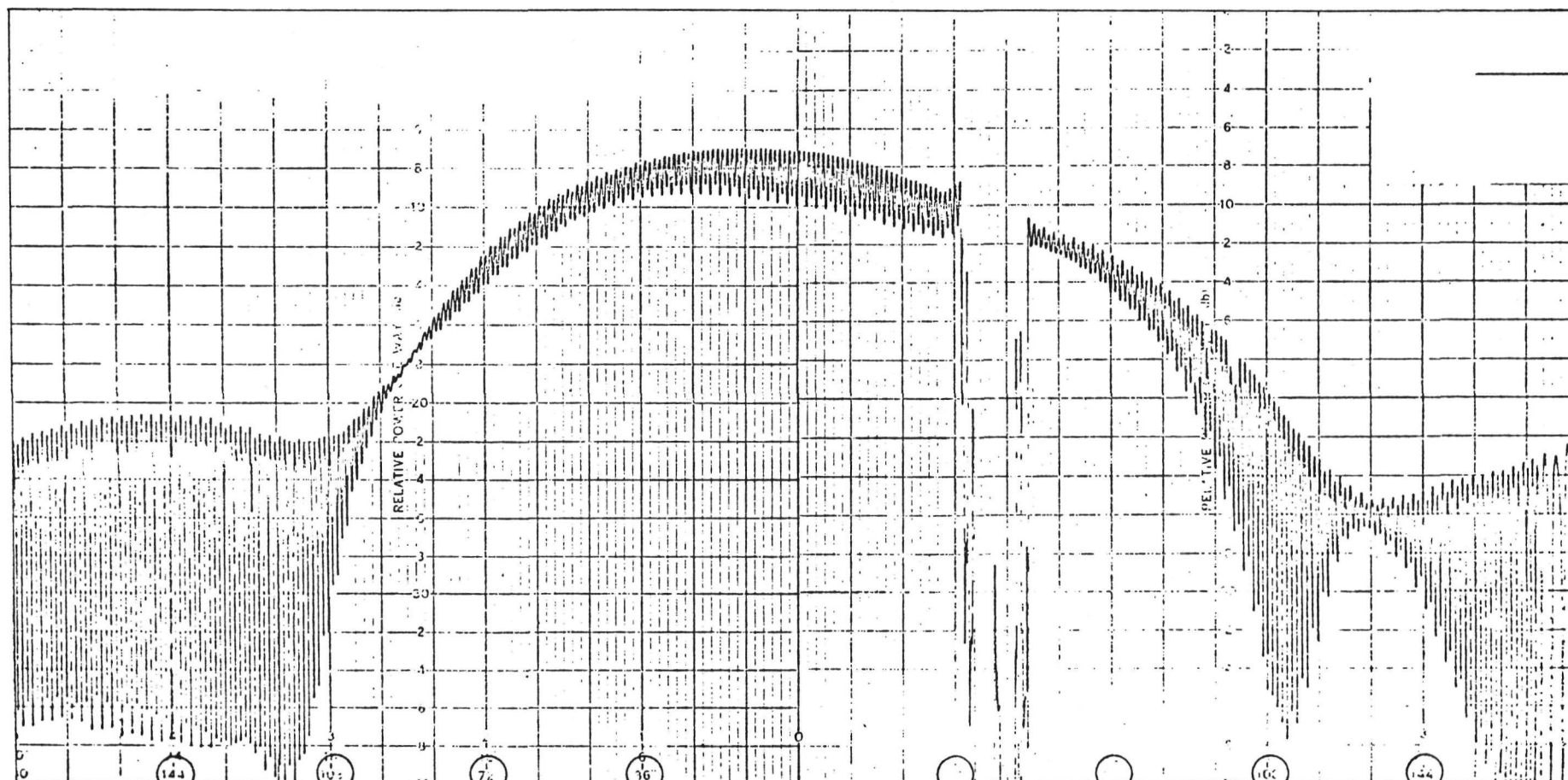Figure 24.   QFH Antenna No. 2 Antenna Pattern.   φ =90° Plane,
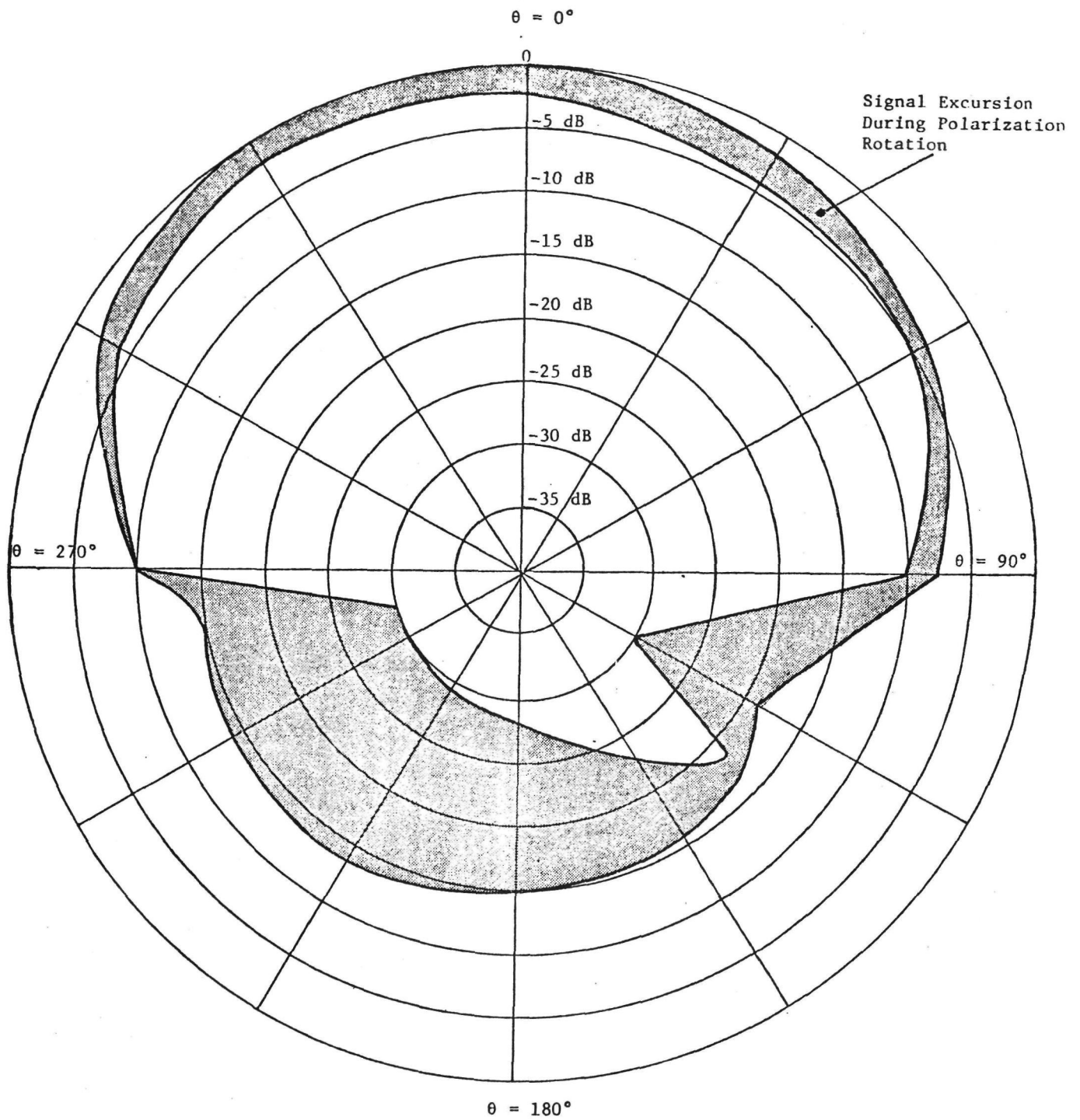Rotating Linear Polarization, 142 MHz.

θ = 0°

0

−5 dB

−10 dB

−15 dB

−20 dB

−25 dB

−30 dB

−35 dB

Signal Excursion
During Polarization
Rotation

θ = 270°

θ = 90°

θ = 180°

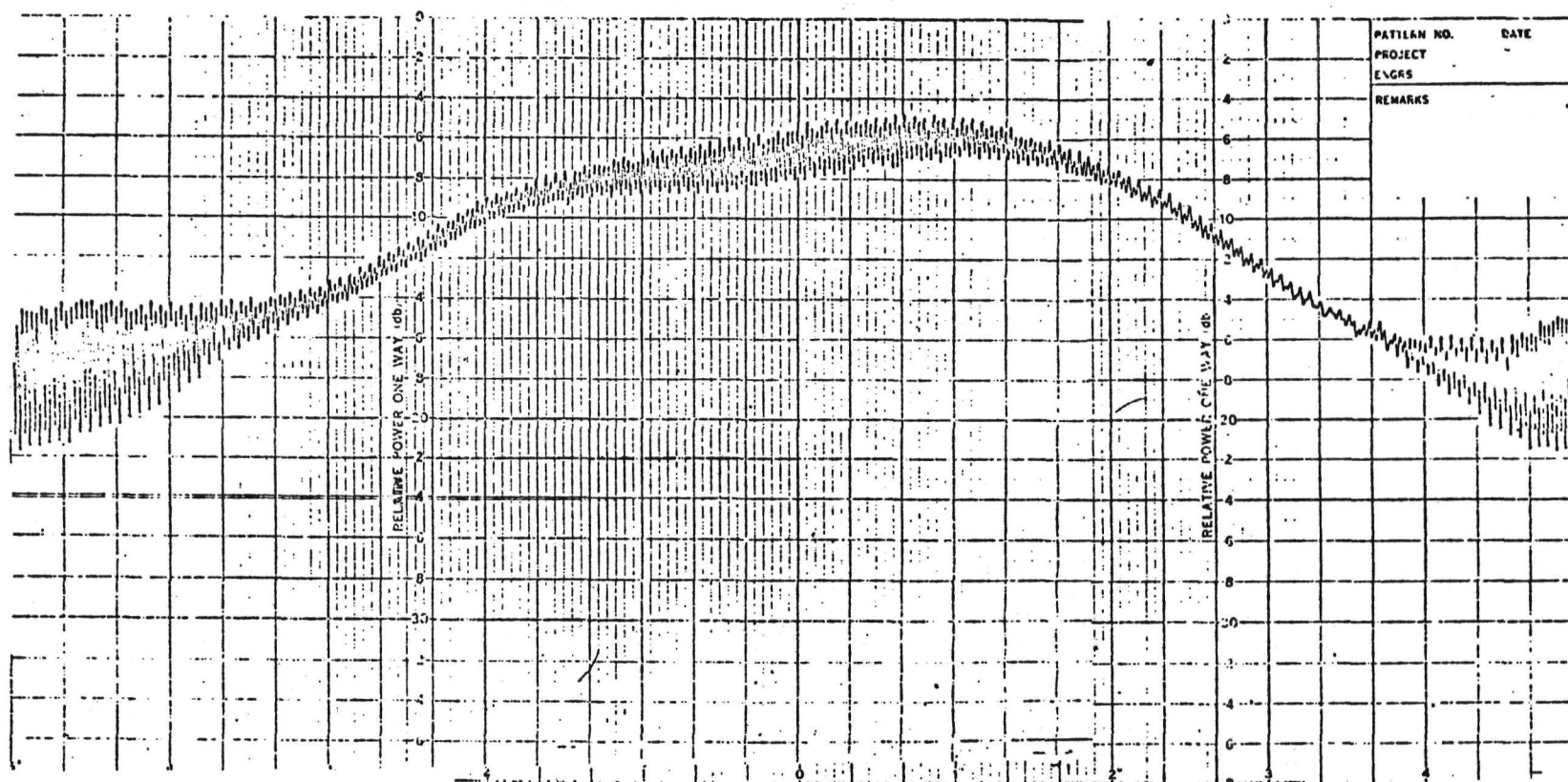Figure 25.   Quadrifilar Helix No. 2 Antenna Pattern. θ Cut, φ = 90°, 142 MHz

Figure 26. QFH Antenna No. 3 Antenna Pattern. $\phi = 0°$ Plane, Rotating Linear Polarization, 142 MHz.
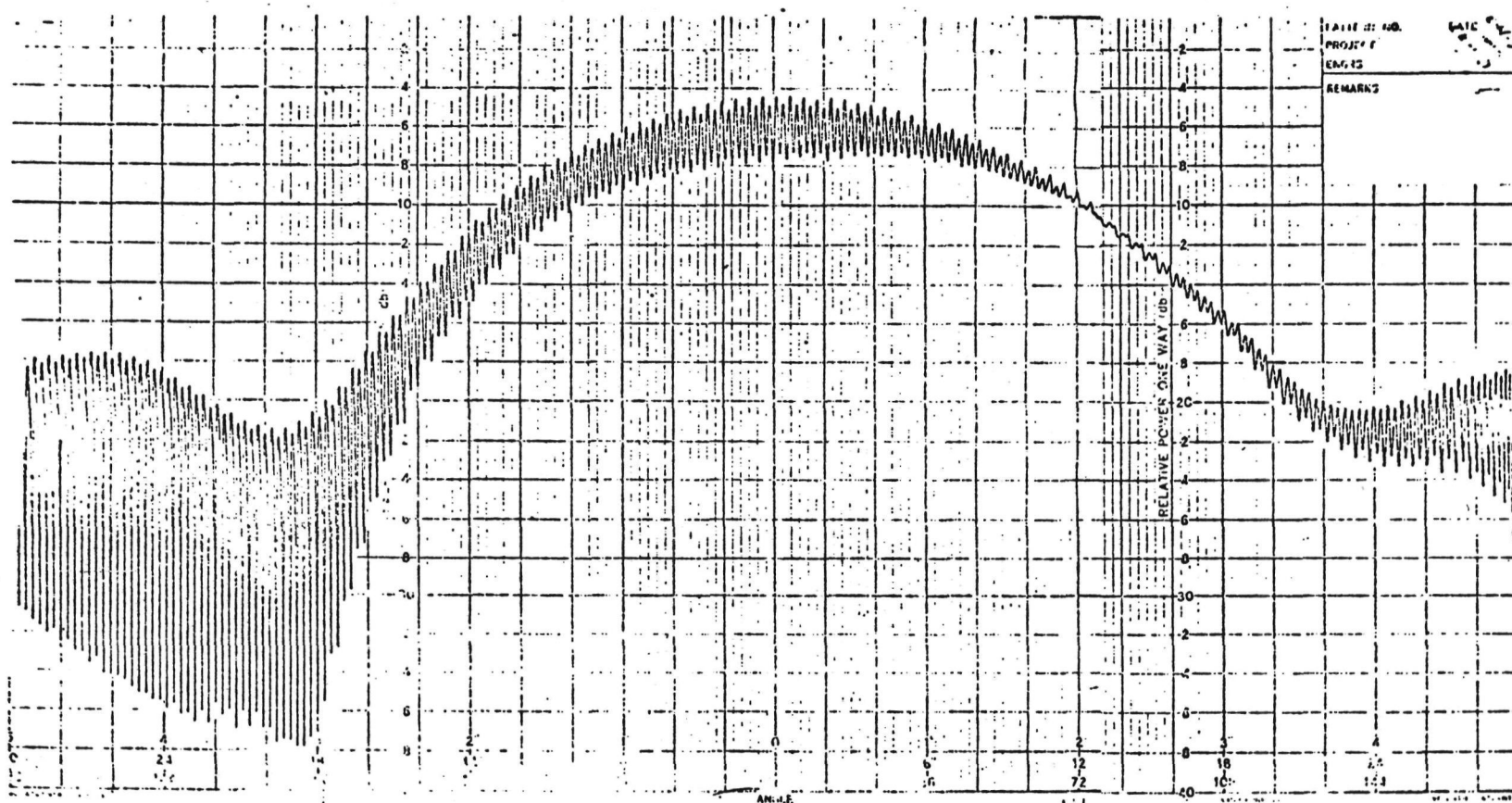
Figure 27. QFH Antenna No. 3 Antenna Pattern. φ = 90° Plane, Rotating Linear Polarization, 142 MHz.
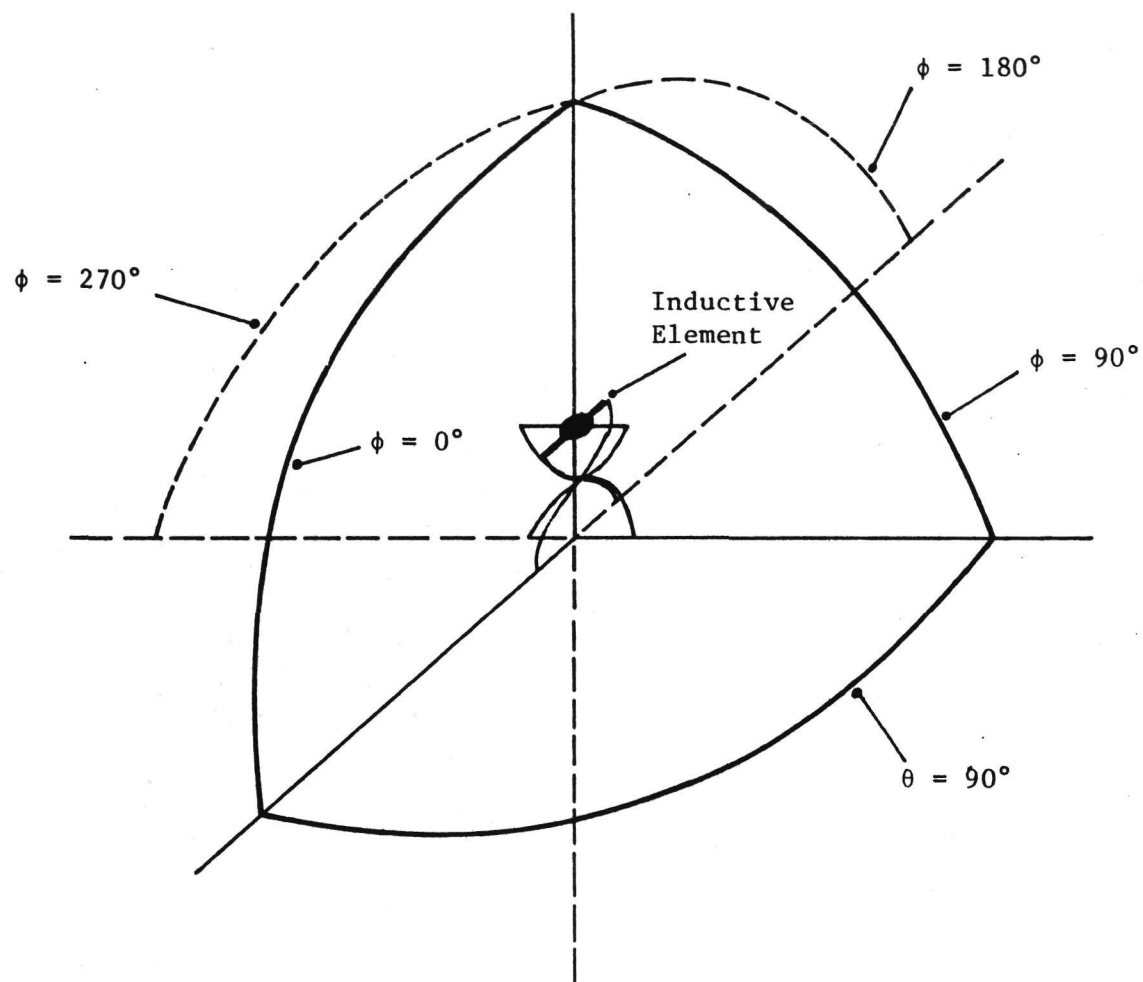
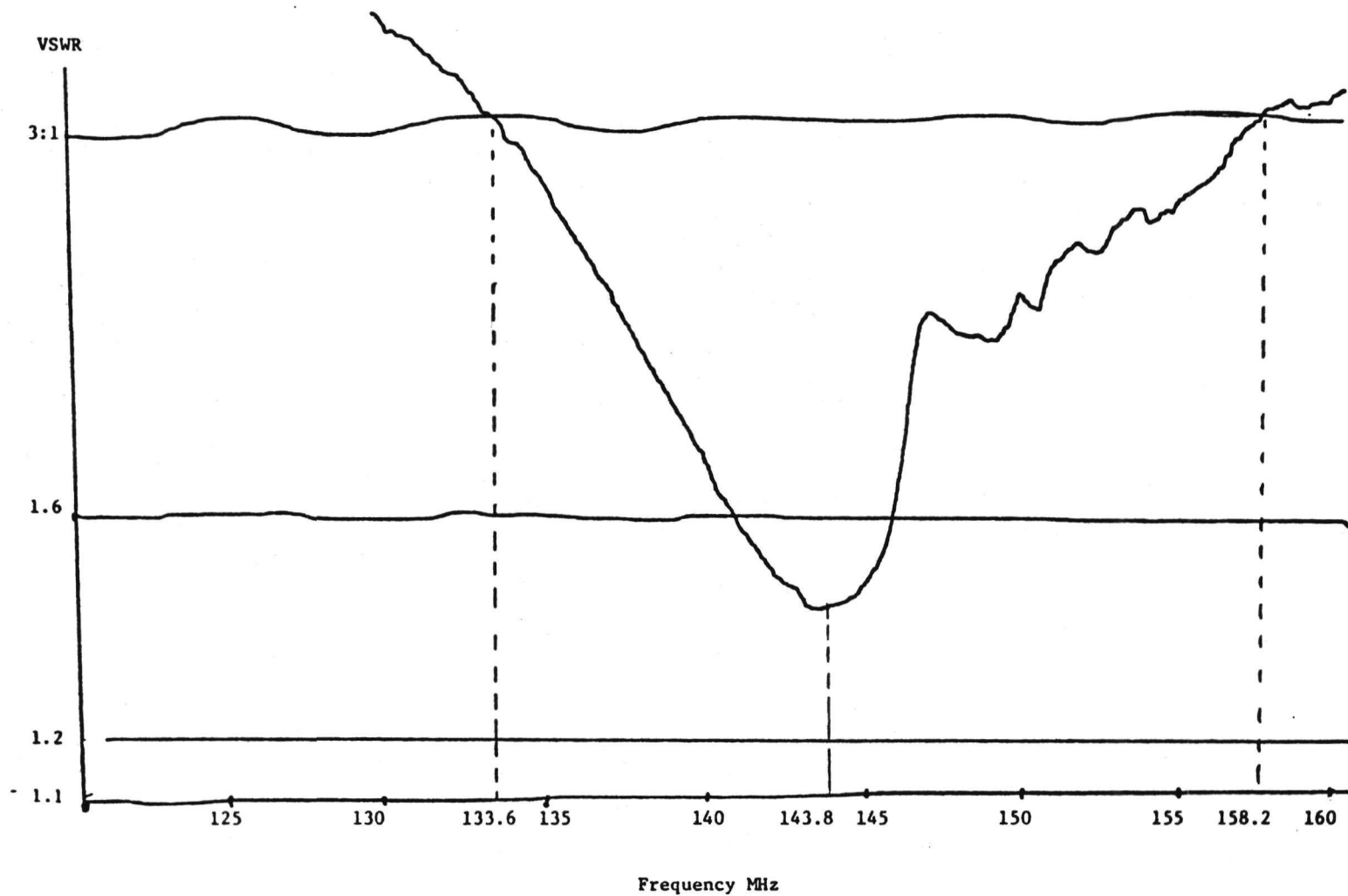Figure 28. Antenna Pattern Coordinates.

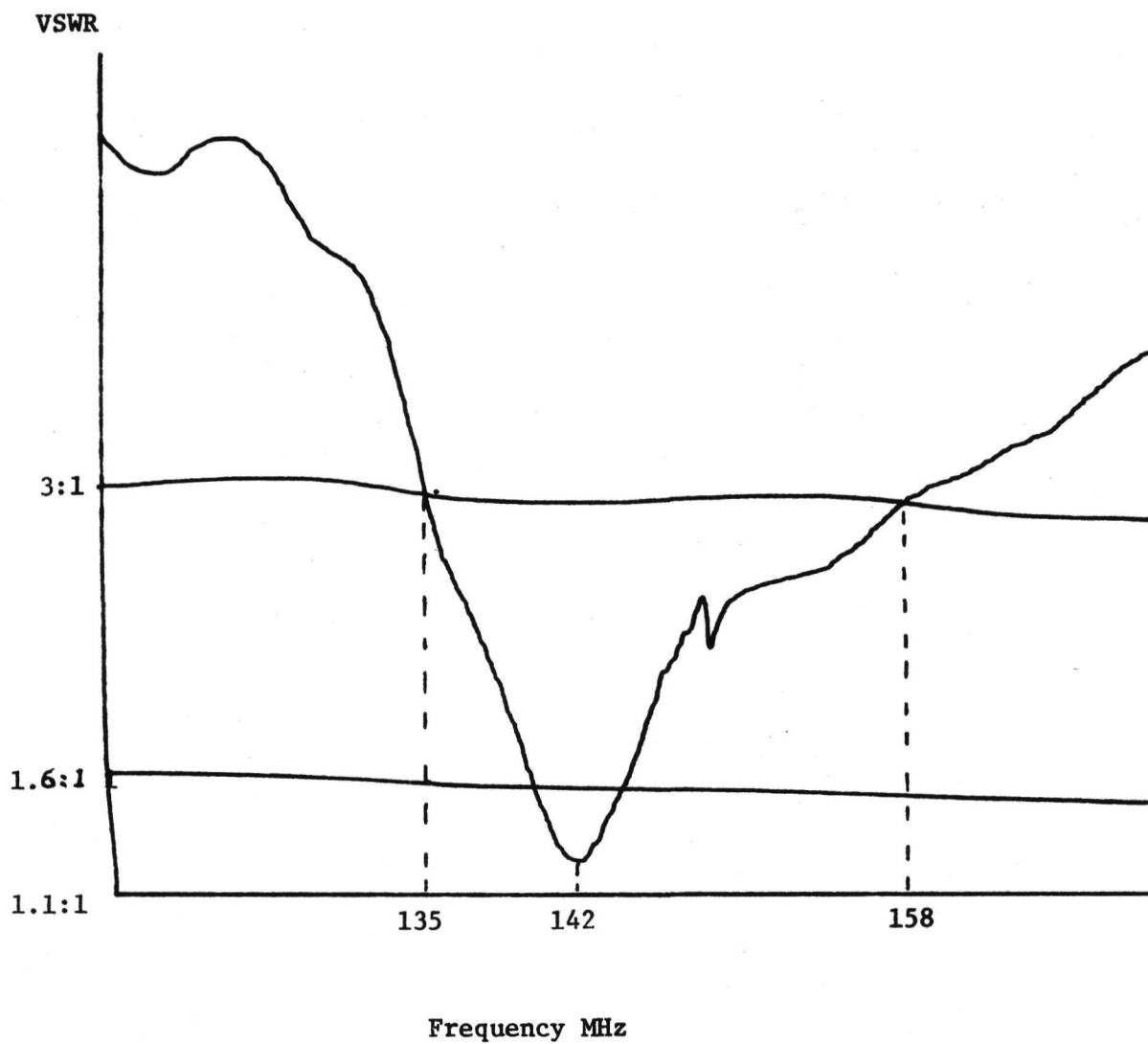Figure 29.   VSWR Plot For Quadrifilar Helix No. 2.

Figure 30.   VSWR Plot For Quadrifilar Helix No. 3.

TABLE 3

REQUIRED VERSUS ACHIEVED PERFORMANCE OF
QUADRIFILAR HELIX – NASA PRIME CONTRACT NAS5-22953

PARAMETER	REQUIREMENT	ACHIEVED RESULTS	REMARKS
CW Power Maximum	300 Watts	300 Watts (Calculated)	Rating of UT 141 Coax Derated by a factor of 2
VSWR Bandwidth	135 to 150 MHz (at 2:1)	133.6 to 158.2 MHz (at 3:1)	Measured
Polarization	RHC, -3 dB @ $\pm$ 60°	RHC, -1 dB at $\pm$ 60°	Measured
Horizon Gain	-6 dB Relative to Zenith	-7 dB Relative to Zenith	Measured
Overall Gain	0 dB	0 dB	Estimated
Size	16" dia by 36" long	16-1/8" dia by 21-3/8" long	Measured
Structural Integrity	Withstand 80 mph Winds	Will Withstand 80 mph Winds based on calculations	Approximate area is 1.4 ft^2 producing 35 lb force in 80 mph winds
Materials	Non-corrosive	Epoxy coated copper and fiberglass	

REFERENCES

1. Frank, P., "Viking Orbiter Antenna Subsystems, Relay Antenna", Vol. 3, Philco Ford, Palo Alto, California.

2. Kilgus, Charles C., "Shaped-Conical Radiation Pattern Performance of The Backfire Quadrifilar Helix", IEEE Transactions on Antennas and Propagation, May 1975.

APPENDIX A

A medium gain 4 element VHF Yagi transmitting antenna was used on Georgia Tech's 1000 foot outdoor antenna range. The relatively narrow beamwidth of this antenna served to minimize range reflections and provided a good signal strength.

Figure A-1 shows the Yagi antenna pattern measured with a rotating linearly polarized source (another 4 element Yagi). Figure A-2 shows a photograph of the Yagi.
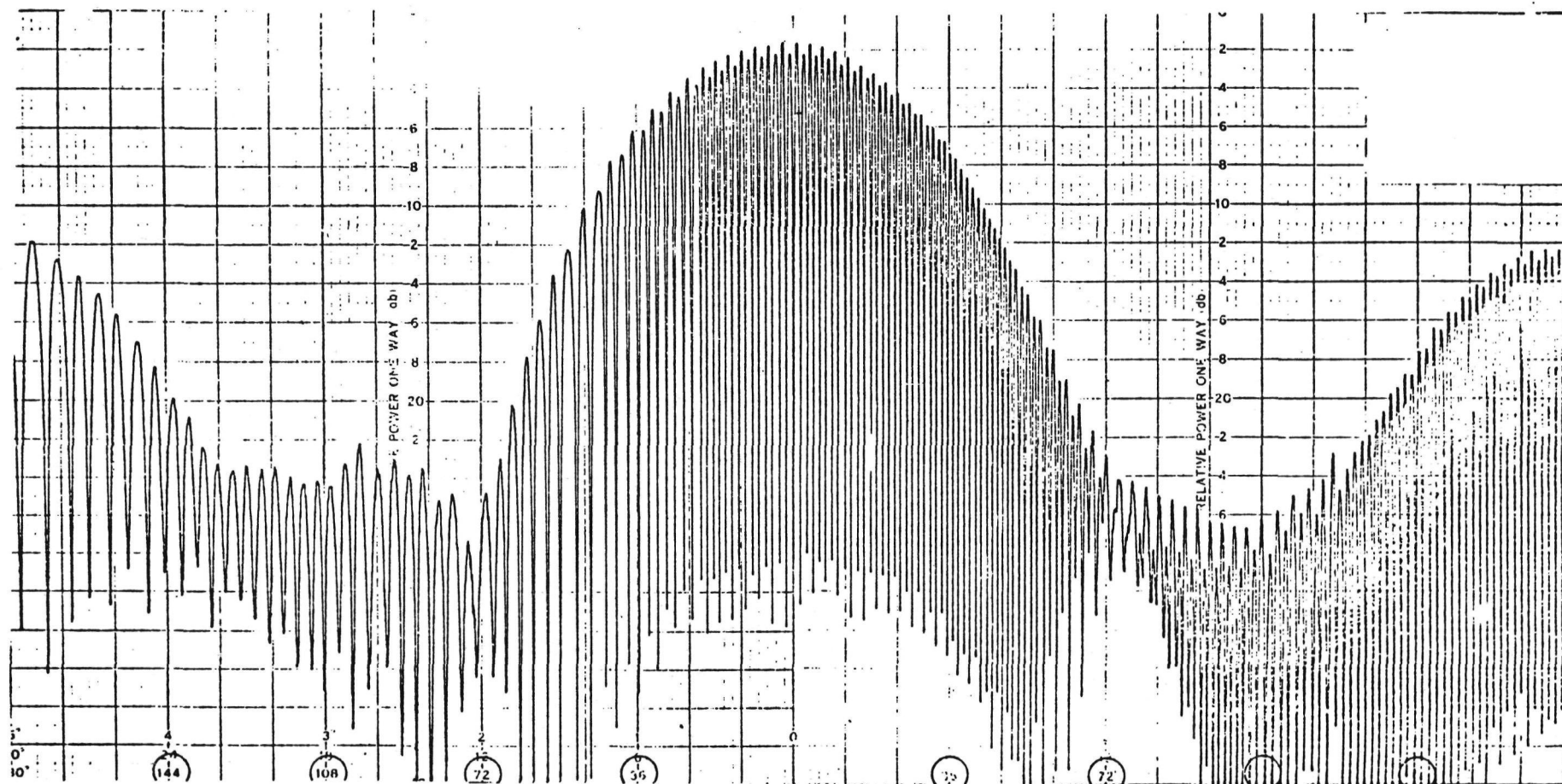
Figure A-1. 4 Element Yagi Transmitting Antenna Pattern
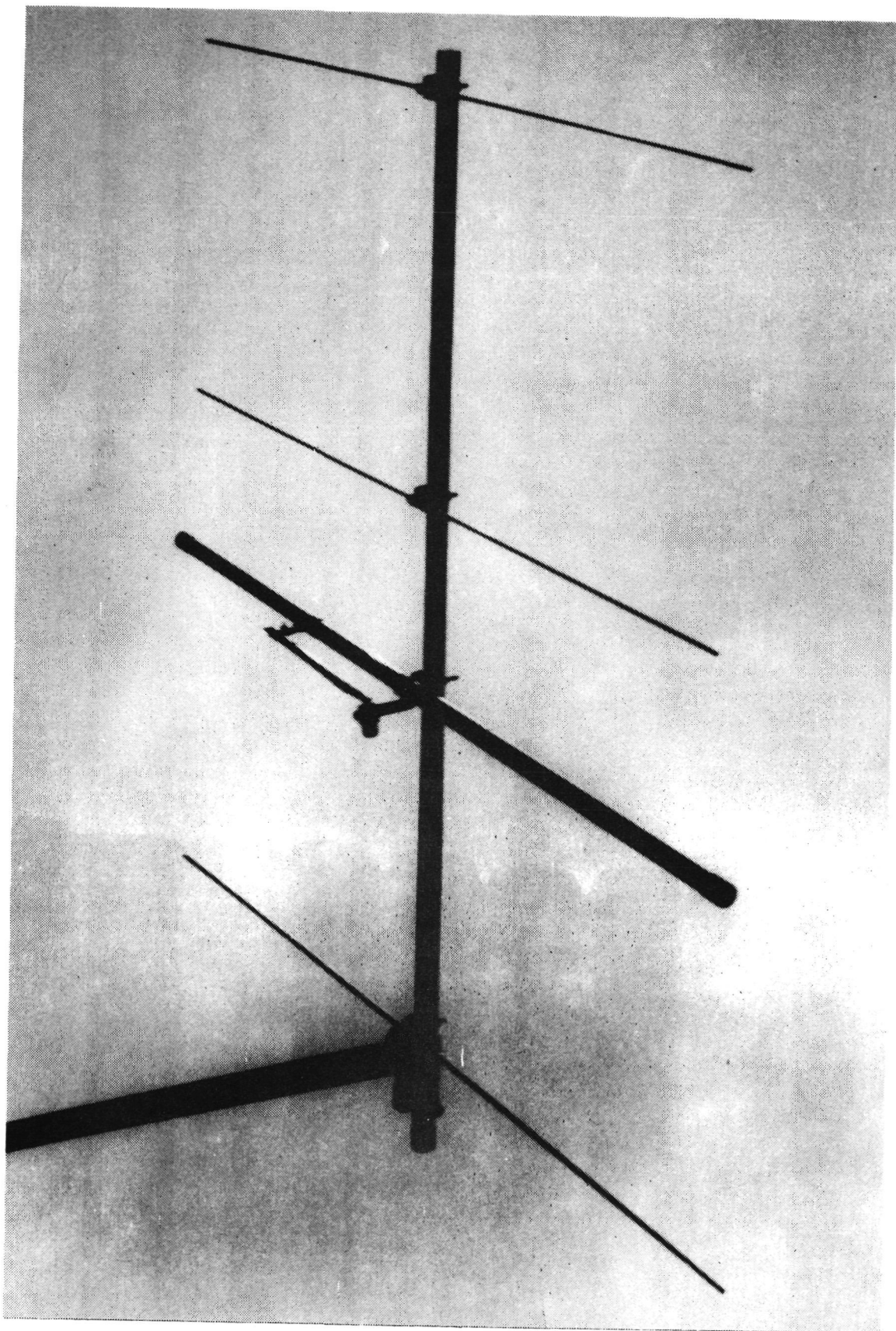E-Plane, Rotating Polarization.

Figure A-2. Photograph of 4 Element Yagi Antenna Used As A Transmitting Source.

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APPENDIX B

Epoxy Enamel Paint Data:

Manufacturer: New York Bronze Power Co.
                Elizabeth, New Jersey
                (201) 289-4900
                Mr. Chuck Hagen (Sales)

QFH Antenna Number 2:

          Type is Epoxy Spray Enamel by Ceramique NO1701 - White

          Pigment 11.67% (Titanium Dioxide 100%)
          Vehicle 58.33% (Epoxy Ester Resin 14.35%, Aromatic
                          Hydrocarbons 32.66%, Chlorinated
                          Hydrocarbons 48.35%, Keytones 9.14%)
          Propellant 30% (Aliphatic Hydrocarbon 100%)

                  _____

                  100%

Do not overpaint with other materials, especially lacquer type paints.